PETROLOGY AND SEDIMENTATION OF THE ARCHEAN SEINE GROUP CONGLOMERATE AND SANDSTONE, WESTERN WABIGOON BELT, NORTHERN MINNESOTA AND WESTERN ONTARIO

A THESIS
SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF THE UNIVERSITY OF MINNESOTA

BY
JAMES R. FRANTES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF SCIENCE

FEBRUARY, 1987

ABSTRACT

Petrology and Sedimentation of the Archean Seine Group Conglomerate and Sandstone, Western Wabigoon Belt, Northern Minnesota and Western Ontario

The Seine Group conglomerate and sandstone are part of the Wabigoon Volcanic Superbelt (Subprovince), located in northern Koochiching County in Minnesota and the Fort Frances-Mine Centre area in western Ontario. This fault-bound wedge of complexly interbedded rocks, that comprises a belt of Archean metasedimentary and metavolcanic rocks, is located north of the Rainy Lake-Seine River Fault and south of the Quetico Fault. The Seine Group occupies a narrow belt both in Minnesota (approximately 16 km by 0.9 km), and in Ontario (approximately 36 km by 2 km). The sedimentary rocks of the Seine Group include orthoconglomerate, feldspathic sandstone, and minor mudstone and banded iron-formation.

A. C. Lawson was the first to record geological investigations in the area. Poulsen and others suggested the Keewatin metavolcanic unit is the oldest unit in the area. The Seine Group nonconformably overlies the metamorphosed plutonic rocks (Lawson's Laurentian) in the eastern part of the study area near Mine Centre.

All rocks in the area have undergone at least greenschist facies metamorphism. Bedding consistently strikes east-northeast and dips nearly vertical. Foliation has a similar trend throughout the study area. Criteria such as cross-bedding, graded bedding, load casts, and vesicular texture in the tops of lava flows usually indicate top to the south. Lineations are usually found in the foliation plane and vary in plunge from 30-70 degrees to the east-northeast.

In the eastern part of the study area, clasts within the conglomerate are more deformed than the conglomerate clasts in the western part of the study area. Megascopic modal analyses, carried out on field exposures, showed that volcanic cobbles and pebbles are the most abundant clasts, usually of felsic to intermediate compositions. Felsic plutonic clasts within the conglomerate are identical to the nearby plutons. Volcanic sandstone interbeds have nearly the same composition, as indicated by microscopic modal analyses, as the conglomerate itself. In the eastern part of the study area, schistose feldspathic sandstone part of the study area, consisting of muscovite biotite schist, overlies the conglomerate.

Modal analyses of the feldspathic sandstone yield an average of 50 percent quartz, 18 percent rock fragments, and 15 percent plagioclase. Cobaltinitrite staining of thin section heels shows an average of less than 2 percent alkali feldspar while Amarand yields approximately 17 percent plagioclase.

The feldspathic sandstone is characterized by abundant cross-bedding, poor to moderate sorting, subrounded grains, immature compositions and a fairly high percentage of matrix material. Cross-stratification is mostly of low to high angle trough type. Paleocurrent measurements are unimodal and suggest paleocurrents were flowing to the present-day south. Using modern sedimentological criteria it is proposed that the Seine Group was deposited as a middle to distal alluvial fan and related braided fluvial environment.

ACKNOWLEDGEMENTS

Many individuals and groups have been helpful in conducting this study and preparing the manuscript. The study was made possible with financial asssistance from the Department of Geology, University of Minnesota. The assistance and cooperation from the Department of Geology is gratefully acknowledged. Additionally, assistance from the Ontatio Geological Survey and the Minnesota Geological Survey is acknowledged. Several persons deserve recognition for their assistance and suggestions in the field including Tim Brown, Rob Cotter, Bill Eggert, Tom Fitz, Mary Meagher Linscheid, and Steve Rasmussen.

I would like to recognize and thank committee members Dr. David G. Darby and Dr. Dave Southwick for their review and support throughout. This project would not have been possible without the excellent input and assistance from my adviser, Dr. R. W. Ojakangas. The direction, guidance, and patience provided by him are most sincerely appreciated.

Special thanks goes to my wife, Sherry, whose support and skill helped to complete this project. Finally, I am most grateful to my parents, Tom and Betty Frantes, for their support and guidance over the years. All accomplishments throughout life are a result of their concern and guidance.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

Chapter 1

INTRODUCTION

The purpose of this investigation was to study the origin of metamorphosed conglomerates and sandstones in the Rainy Lake area. The area lies in the northern part of Koochiching County in Minnesota, and the Fort Frances-Mine Centre area in western Ontario (Figure 1.1). The rocks are located in the southern Wabigoon Subprovince, near the boundary zone with the Quetico Subprovince of the Superior structural province, just north of the Rainy Lake-Seine River fault. In Minnesota the study area is a narrow belt about 0.9 km wide and 16 km long extending east-northeast. Metasandstone and metaconglomerate occupy the same stratigraphic position 27 km to the east-northeast in Ontario, continuing for another 36 km eastward.

The Quetico and Rainy Lake-Seine River faults bound a wedge of complexly interbedded rocks that comprise a greenstone belt of Archean metavolcanic and metasedimentary rocks along the southern edge of Rainy lake, and extending to the northeast in Canada. The fault-bound wedge is structurally discordant from both subprovinces but because of general lithological similarity it is usually considered part of the Wabigoon

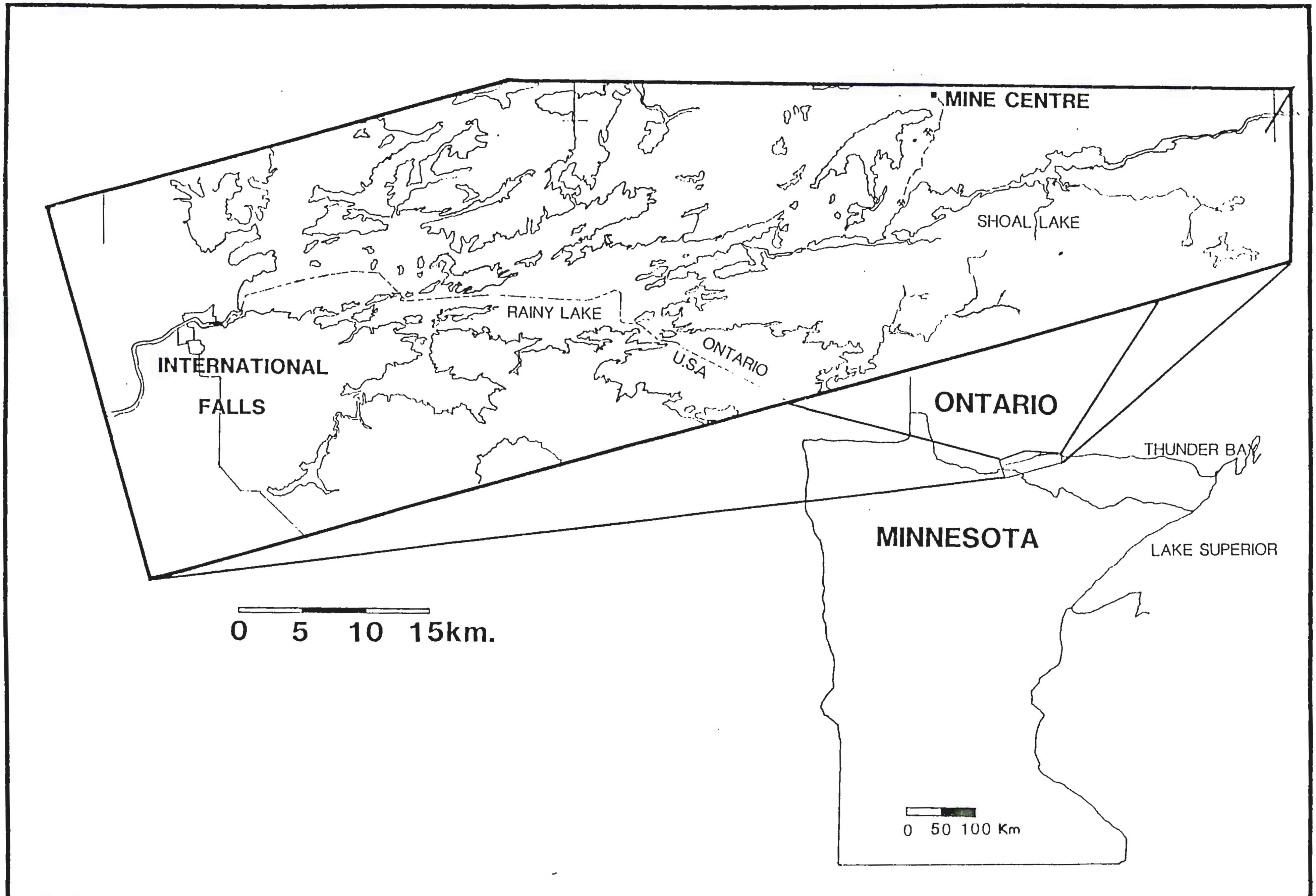

Figure 1.1 Location Map of the area of study.

subprovince (Poulsen, 1984). Mineral exploration in the area dates back to the 1880's. Although interest in mineralization has resulted in an abundance of literature, very few quantitative data regarding the metasedimentary rocks are available. This study of the metamorphosed conglomerate and sandstone units was undertaken to obtain data from which the origin of these rocks can be inferred. Objectives of the study are: to describe the metasedimentary rocks on both a microscopic and megascopic scale, obtain quantitative compositional and textural data, and to add to the information about the origin of the rocks and characteristics of the source rocks and early crust. Detailed geologic maps produced by Lawson (1913), Ojakangas (1972), Wood and others (1980), Poulsen (1984), and Day (1984) were used as bases; where checked in the field, all were found to be accurate. Detailed mapping was not a part of this investigation; the maps included have been revised from previous workers.

Because the objectives of this project deal with sedimentation, original pre-metamorphic rock terminology is generally used.

Regional Geology

The bedrock geology of the region is divided into three parts by the two major faults. North of the Quetico fault the rocks are metavolcanic migmatite and granitic intrusions (Wood, 1980). South of the Seine River-Rainy Lake fault the rocks are metasedimentary, mostly biotite schist, intruded by minor granitic rocks that constitute the northernmost outliers of the Vermilion granitic complex. Between the Quetico and Rainy Lake-Seine River faults is a sequence of low-grade metavolcanic and metasedimentary rocks, intruded by granitic plutons. The metavolcanic lithologies are flows, pyroclastic, and epiclastic rocks of mafic to felsic composition. Metamorphosed sedimentary rocks include conglomerate and sandstone, plus minor mudstone and iron-formation. With the exception of a few northwest-trending dikes, the rocks of the Rainy Lake district are all Archean in age. Nearly all of the layered rocks in the study area dip vertically, and evidence exists for more than one period of folding. The low metamorphic grade has resulted in the preservation of many primary textures and sedimentary structures.

Previous Work

Mineral exploration in the Rainy Lake area dates back to the 1880's. In 1887 the Canadian Pacific Railroad provided access to Rainy Lake and the lower Seine River area. At the same time a gold rush in northern Minnesota overflowed into the area. By 1900 virtually every piece of land between Little Turtle River and Shoal Lake was covered by a surveyed mining location (Poulsen, 1984).

A.C. Lawson (1888) was the first to carry out geological investigations in the area. Two periods of folding and igneous activity, the Laurentian and Algoman, were recognized by Lawson. Each was followed by uplift and erosion. Table 1.1 shows Lawson's (1888) stratigraphic interpretation. His oldest division was the Laurentian orthogneisses, upon which the Coutchiching was deposited. Lawson designated the metagreywacke and slate in the southern portion of the volcanic-sedimentary belt as the Coutchiching Series and noted that it lies unconformably beneath the Keewatin greenstone. The Keewatin was defined as a thick sequence of volcanic (mafic to felsic) rocks, with local clastic and chemical sedimentary rocks. Conglomerate and subarkosic arenite overlying the Keewatin were assigned to the Seine Series. Lawson was the first to document that the conglomerate was lying on an erosion surface developed upon Keewatin metavolcanics and tonalite that was intrusive into the volcanics. Lawson tried to differentiate the intrusive rocks as Laurentian or Algoman.

In 1904 a special international committee (Van Hise and others, 1905) visited the area, and concluded that the Coutchiching schists overlie, rather than underlie, the

LAWSON (1913)	GROUT (1925)	HARRIS (1974)	PRESENT STUDY
Keweenawan Dikes		Felsic and Intermediate Intrusives	Mafic Dikes
Algoman Granites	Algoman Granites	Early Intrusives	Intrusives
Seine Series	Huronian Metasediments	Metasediments	Seine Group Metasediments
Laurentian Tonalites	Laurentian Granite-Gneiss		Metamorphosed Intrusives
Keewatin	Archean Greenschist	Metavolcanics	Metamorphosed Graywackes
Coutchiching	Coutchiching	Lower Metasediments	Keewatin Metavolcanics

Table 1.1 General stratigraphic interpretations of the Rainy Lake area by several workers (After Poulsen and others, 1980).

Keewatin greenstones. However, Lawson's (1913) restudy of the area affirmed his original earlier convictions about the relative positions of the Keewatin and Coutchiching. Grout (1925) proposed a stratigraphic model nearly identical to Lawson's and called the Seine Series "Huronian" metasediments.

Merritt (1934) concluded that the Coutchiching lies unconformably on the Keewatin series. He put Lawson's Coutchiching and the Shoal Lake conglomerate into the Seine Series. According to Merritt the conglomerate lies unconformably on the Laurentian rocks which in turn are intrusive into the Keewatin.

The first radiometric age dates for the area, largely K-Ar, were by Goldich and others (1961). Those first studies suggested that Lawson's Laurentian and Algoman were not widely separated in time. More recent radiometric studies include whole rock Rb-Sr data and U-Pb data for zircon and sphene (Tilton and Gruenfelter, 1968; Hart and Davis, 1969; Peterman and others, 1972; and Davis and others, 1986).

Ojakangas (1972) studied the Coutchiching and suggested that the biotite schists were beds of greywacke and mudstone and recognized features such as Bouma sequences, concretions, flame structures, and load casts. He noted that major longitudinal faults separate the main lithologies which either top toward each other or away from each other across the faults, making age distinctions difficult.

Poulsen (1980, 1982, and 1984) studied the controversy and proposed overturned structures at the Rice Bay Dome and other related areas. Other recent investigations include those by Wood (1980), Day (1984), and Davis and others (1986).

Chapter 2

STRATIGRAPHY AND GENERAL GEOLOGY

Stratigraphy

The stratigraphic nomenclature for the Rainy Lake area was established by Lawson (1888). He recognized three major lithostratigraphic units- the Coutchiching,the Keewatin and the Seine. Significant modifications to the stratigraphy established by Lawson were presented first by Grout (1925) and later by other workers. The conflict has become known as the Coutchiching problem (e.g., Ojakangas, 1972). Lawson interpreted the Coutchiching series of metasediments to be overlain by the Keewatin metavolcanics. These rocks were folded and intruded by granitic rocks which Lawson called older or Laurentian granites. Uplift and erosion of this complex resulted in the deposition of the Seine Series (upper Huronian according to Lawson) comprised of conglomerate and sandstone. A second period of folding affected the sequence; Lawson called plutonic activity associated with this the Algoman. He emphasized that there were two periods of orogeny accompanied by magmatic activity.

Grout's interpretation of the stratigraphic pile challenged Lawson's by placing the Coutchiching metasediments with the Seine Series. Harris (1974) followed Lawson on the lower part of the pile but disagreed regarding the Laurentian and Algoman intrusive activity.

General Geology

All rocks in the area have undergone at least upper greenschist facies regional metamorphism (Lawson, 1913). Criteria such as cross-bedding, graded bedding, load casts, vesicular texture on top of lava flows, and foliation refraction indicate topping directions in the study area are usually to the south. Evidence for two periods of folding is common. Dip-slip and strike-slip faults usually parallel trends of subprovinces and rock units (Ojakangas, 1972).

Gold has been produced from small mines in the region, known as the Lower Seine gold region. Deposits are concentrated along subprovince boundaries and are related spatially to the major faults and their splays (Poulsen, 1984). Low-grade iron-formations are present in the area, and are also concentrated near the subprovince boundaries. Poulsen (1984) recognized two types of deposits containing base metals in the Ontario portion of the greenstone belt, but very little base metal production has been reported:

1) Zinc-copper mineralization at specific horizons within the metavolcanic successions, and

2) Copper- Nickel mineralization associated with mafic and ultramafic intrusions.

Keewatin Group Metavolcanics

The oldest unit in the area is the metavolcanic unit known as the Keewatin Group (Poulson and others, 1980). The metavolcanic group consists of lower mafic units, middle intermediate units and upper felsic units (overlain by local ultramafic metavolcanics), and includes extrusive and intrusive rocks (basalts, diabase sills, rhyolites, and rhyodacites).

In the western part of the Wabigoon subprovince, detailed stratigraphy shows an evolution through time from mafic tholeiitic flows with few volcaniclastic sedimentary rocks to more silicic calc-alkaline pyroclastic rocks, in part subaerial (Blackburn and others, 1985).

Metamorphosed Greywackes and Mudstones

The greywackes and mudstones have been metamorphosed to biotite schists of variable grain size. The biotite schist is present as 4-18 cm thick beds; locally, beds are as thick as one meter. The schist south of the Rainy Lake-Seine River fault is generally coarser-grained than that to the north. The metagreywackes, particularly south of the fault, show Bouma sequences; Ojakangas (1972) noted that these show many features of turbidites. Wood (1980) suggested the correlation of the metagreywackes and the feldspathic sandstone north of the fault with the biotite schist of the Quetico subprovince to the south.

Metamorphosed Plutonic Rocks

Lawson termed these rocks Laurentian because they invaded the Keewatin and the Coutchiching and contributed sediment to the Seine Series (Lawson, 1913). These are small elongate sheared, and altered tonalitic plutons that are commonly enveloped by metavolcanic rocks (Peterman and others, 1972); examples are the Grassy Island Tonalite and the Bad Vermillion Pluton (Plates 1 and 2).

Seine Group Metamorphosed Conglomerate and Sandstone

The Seine Group is the youngest supracrustal sequence in the area, and is the subject of this investigation. The group is comprised of metamorphosed conglomerate and sandstone unconformably overlying the metamorphosed plutonic rocks. The unconformity is a nonconformity, as these metasediments lie on an erosional surface on the plutonic rocks. The conglomerate is fairly well exposed on Neil Point (Minnesota) in road cuts and along some ridges. It is also fairly well exposed along Highway 11 north and northeast of Shoal Lake in Canada; in most areas, clasts are deformed, stretched, or sheared.

Granitic Rocks

The plutonic rocks which Lawson termed Algoman consist mostly of quartz monzonite and quartz diorite. Based on size, contact relations, and the low metamorphic grade of the country rocks, these plutons were interpreted by Peterman and others (1972) to have been emplaced at high levels in the crust.

Mafic Dikes

Diabase dikes in the area dated by Hanson (1968) have a K-Ar age of 2100 m.y. Poulsen and others (1980) suggested that they represent a wide spectrum of ages and origins.

Discussion

Lawson's decision to place the Coutchiching below the Keewatin as the oldest unit was based on the structural superposition seen in Rice Bay. Until Poulson and others' (1980) structural interpretation, most workers accepted either Lawson's or Grout's stratigraphic interpretations. Many of the more recent studies suggest that the metavolcanics of the Quetico subprovince and the Coutchiching greywackes are time-stratigraphic equivalents.

Poulsen and others (1980) suggested that younging directions (based on graded beds and pillows) indicate that some antiforms are antiformal synclines and that some synforms are synformal anticlines. This is supported by overturned contacts and downward-facing F2 folds. Because of this complexity, they showed that structural superposition does not portray the stratigraphic relationships and that Lawson's interpretation was not correct. Lawson's interpretation was based on the fact that Coutchiching metasediments occupy the cores of antiforms.

Based on the work of Poulsen and others (1980), the present study follows the stratigraphic interpretation presented in Figure 2.1. This revised stratigraphic column is based upon Poulsen's work (1981 and 1984), data obtained from the Ontario Geological Survey Maps P.2201 and P.2202 (1980), Day (1984) of the USGS, and my own observations. The Coutchiching of Lawson now appears to overlie the Keewatin Group.

Ages

Figure 2.2 is a summary of radiometric ages for the area. Hart and Davis (1969) concluded that all rock-forming events between the development of the volcanic-sedimentary pile and the intrusion of Laurentian rocks occurred in less than 50 m.y. Hart and Davis (1969) dated four samples of Laurentian tonalite and anorthosite to get a Rb-Sr age of 2520 +/- 100 m.y. They suggested that these have been open systems and have responded to a later event. The oldest ages reflect widespread igneous activity, while the younger age determinations are a

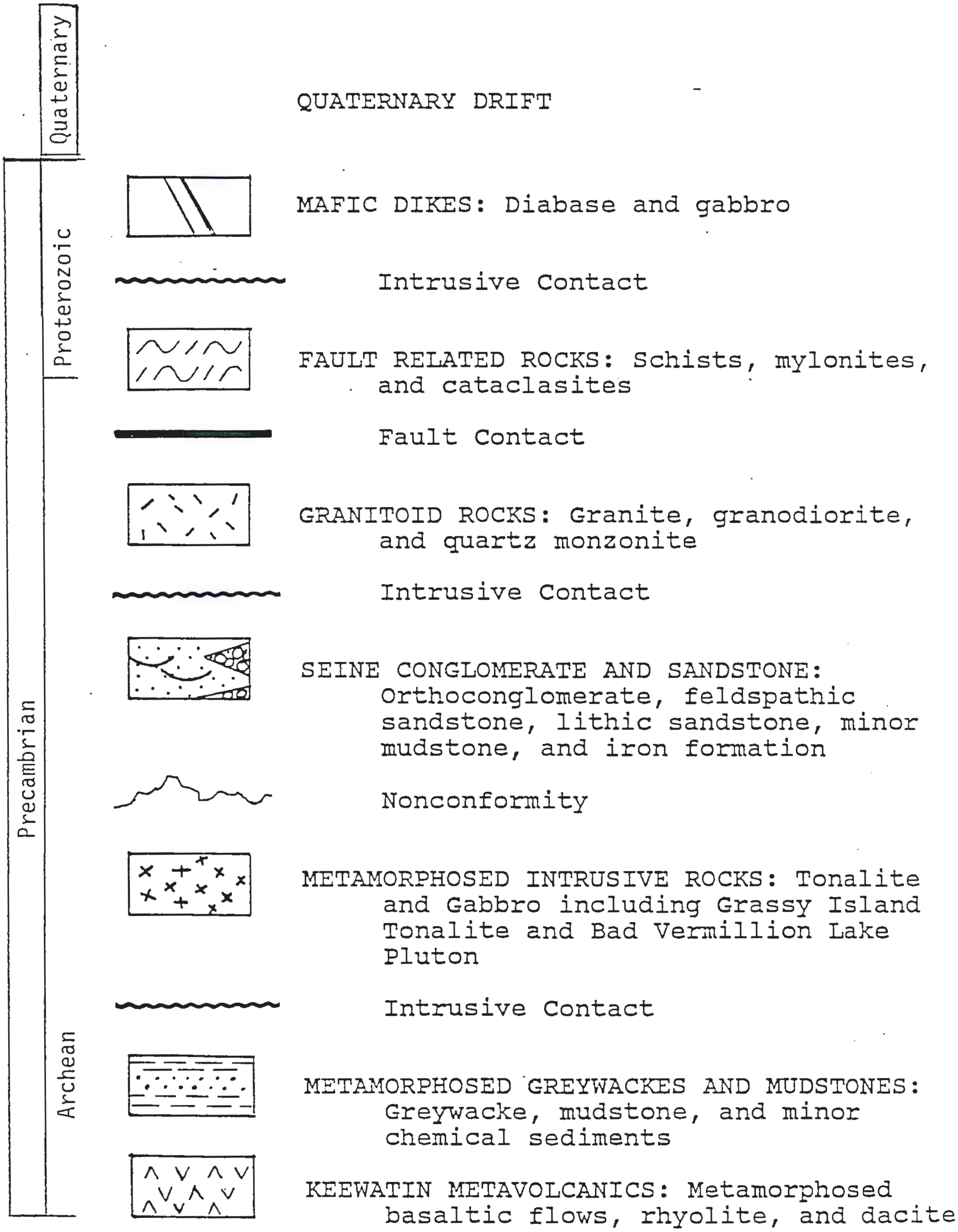

Figure 2.1 Generalized stratigraphy of the Rainy lake area (After Poulsen, 1984).

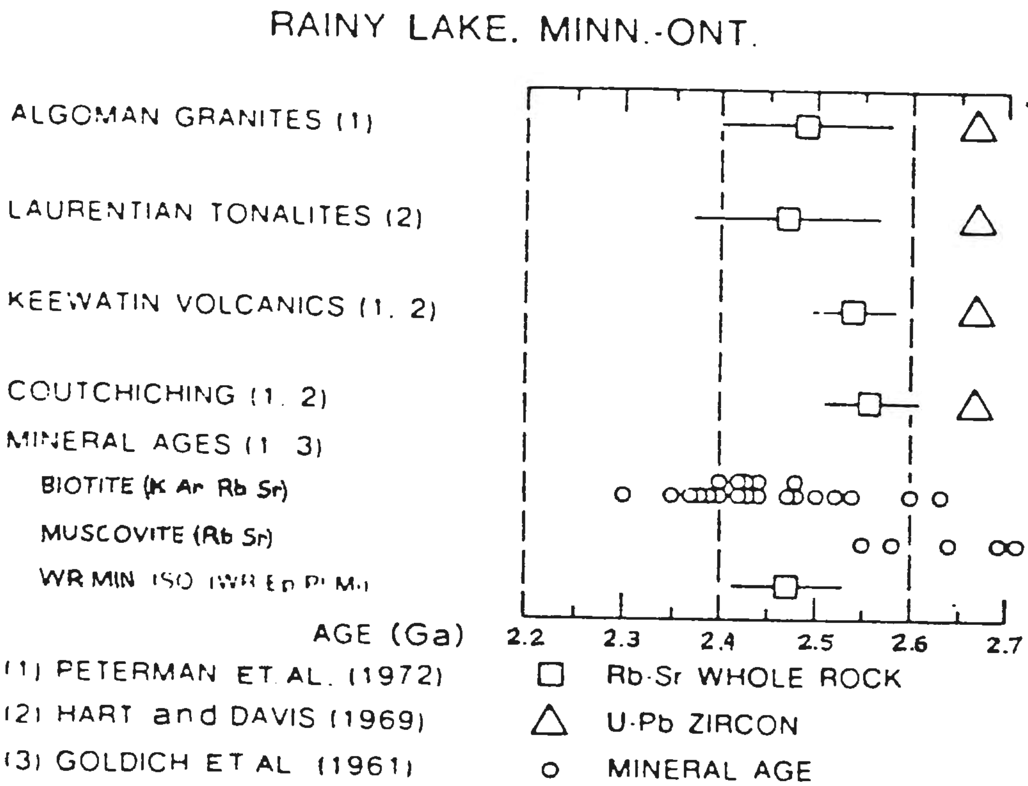

Figure 2.2 Summary of radiometric ages for the Rainy Lake area (From Goldich and Peterman, 1980).

result of metamorphism, metasomatism and uplift.

Hart and Davis analyzed three samples of Keewatin metavolcanics (metabasalt, amphibolite, and meta-rhyodacite) that fit an isochron of 2770 m.y. but there is an uncertainty of +/- 330 m.y.

Peterman and others (1972) sampled a diversity of rock types and metamorphic grade, and arrived at an age of 2595 +/- 45 m.y. for the Laurentian intrusives. Rb-Sr ages of Coutchiching paragneisses and of Keewatin metavolcanics are nearly the same at 2615 and 2595 m.y. respectively (Peterman and others, 1972). They suggested that all whole rock Rb-Sr systems have been disturbed by younger events and that none of the isochron ages can be interpreted as dating actual rock-forming events. Peterman and others (1972) interpreted a clustering of ages at about 2500-2600 m.y. as representing a low-grade event or an "epeirogenic" effect. They suggested that zircon and sphene ages for the Laurentian orogeny are no earlier than 2730 +/- 30. Peterman and others call the paragneisses of Rice Bay the oldest rocks in the area, representing metamorphosed graywacke-shale underlying the Keewatin. They suggest sedimentation, magmatic activity, folding and metamorphism were penecontemporaneous at 2750-2700 m.y.

Zircon samples from the Algoman granite of Lawson yield a date fitting the 2710 m.y. concordia chord (Peterman and others, 1972). Most workers agree that magmatic activity in the form of dike intrusion and local structural adjustment continued for a long period of time. A Rb-Sr isochron age for the Vermilion granite is in agreement with U-Pb zircon ages of other Algoman rocks. Peterman and others (1972) found a Rb-Sr date for 13 total rock samples of Algoman granite to define an isochron of 2540 +/- 90 m.y. Mica ages are not concordant. Peterman and others (1972) reported K-Ar ages of biotite from the granites are 2420 m.y.

Day (1984) suggested that all rock-forming events in the area occurred between 2750 and 2600 m.y. Goldich and Peterman (1980) presented the sequence of events depicted in Table 2.1; they put the Coutchiching as the oldest unit underneath the Keewatin, following Lawson, and they also recognized three different intrusive episodes including the mafic dikes. Early efforts to resolve the two orogenic periods on the basis of K-Ar and Rb-Sr age determinations on micas were not successful (Peterman and others, 1972).

Goldich, using an abrasion technique (1984) on zircon and titanite, reported a U-Pb age of 2735 m.y. for tonalite and granodiorite and an age of 2680 m.y. for post-tectonic granodiorite and granite.

Inferred sequence of events

Time (Ma)	Volcanism and sedimentation	Plutonism	Tectonism and metamorphism
> 2100		diabase dikes	regional fracturing
2400—2500			uplift, faulting, local cataclasis, regional cooling
		Algoman granitic plutons, granite dikes and pegmatites	
			folding and regional metamorphism (greenschist to amphibolite facies)
		Rocky Islet Bay Complex	
2600—2700	deposition of Seine Series		
			uplift and folding
		Rice Bay sills	
	Keewatin volcanism	Laurentian tonalites gabbro and related rocks	
	deposition of Coutchiching (multiple sources and unknown basement)		

Table 2.1 Goldich and Peterman's (1980) inferred sequence of events of the Rainy Lake area.

Age relationships based on U-Pb zircon age dating, of a sill near the Rice Bay Dome and the rhyolite at the core of the dome supports the interpretation of the inversion of the stratigraphic sequence (Davis and others, 1986). Furthermore the age for the Bad Vermillion Lake sill was found to be 2729 +/- 3 m.y., similar to the age of 2728 +/- 5 m.y. measured from the overlying rhyolite. Davis and others (1986) dated a trondhjemite clast from the Seine Conglomerate near Shoal Lake yielding an age of 2695 +/- 3 m.y. The dated clast provides a maximum age for the Seine Group.

Chapter 3

UNIT DESCRIPTIONS

Introduction

Much of the area is thickly wooded or covered by lakes and swamp, but outcrop is fair, especially along shorelines. Many of the exposures are covered with lichen and algae which require brushing and bleaching to expose rock surfaces. Some weathered glaciated ledges provide excellent surfaces for detailed study. The general stratigraphic units of the Seine Group are presented in Figure 3.1.

Field Description, Conglomeratic Units 1,2, and 5

The conglomerate is present in one distinct area in the eastern part of the study as shown on Plate 2, in a belt north and east of Shoal Lake. Units 1 and 2, (Plate 2) the lowermost units in the Seine Group, consist of a polymict orthoconglomerate (clast-supported) containing abundant volcanic and plutonic cobbles. Most volcanic cobbles are felsic to intermediate, but some mafic cobbles are present. Near shear zones, the more imcompetent clasts are intensely deformed. In the eastern part of the study area, less competent clasts are more deformed, with elongation ratios as high as 15:1. Figure 3.2 shows the Unit 1 conglomerate

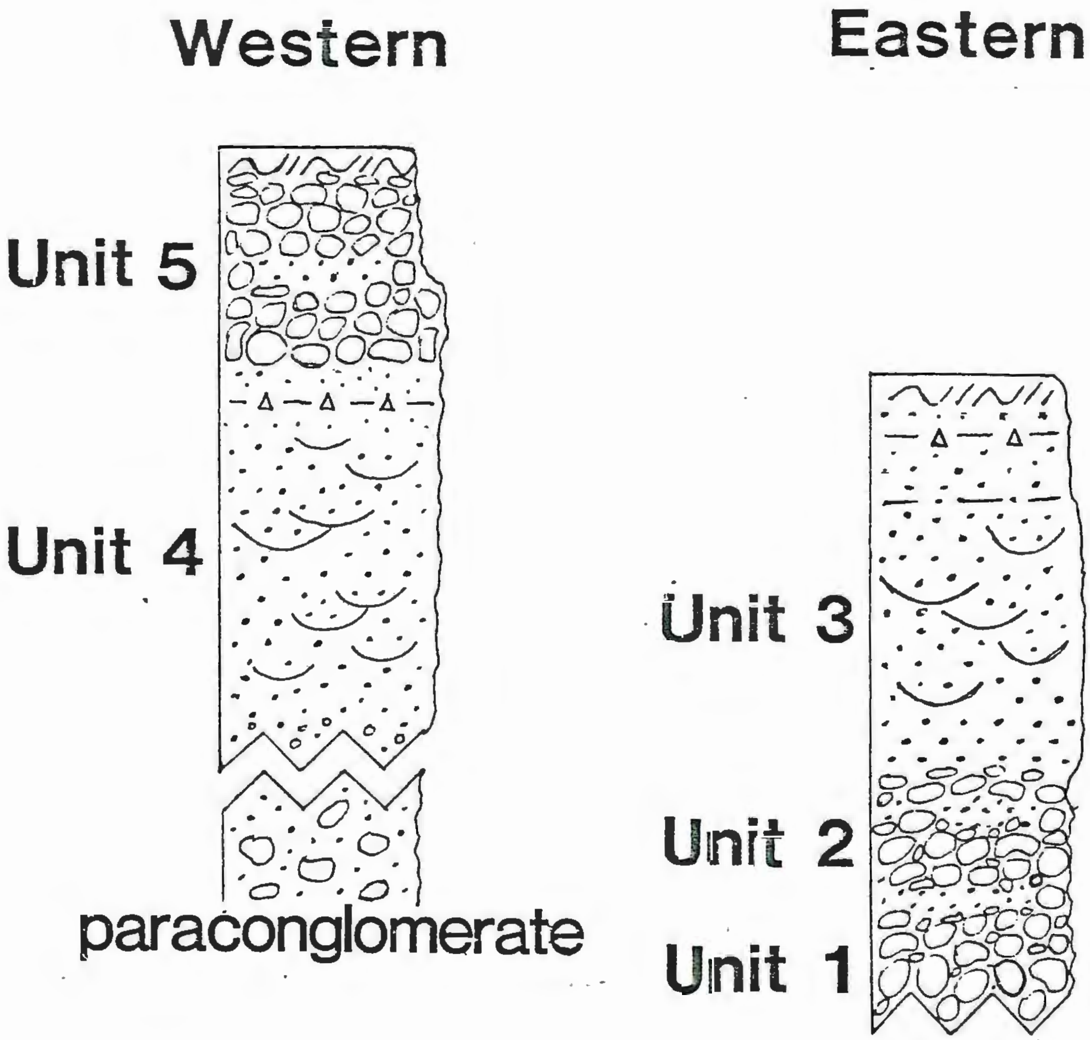

Figure 3.1 Stratigraphic units of the Seine Group.

Figure 3.2 Conglomerate outcrop exhibiting extremely deformed clasts located near Highway 11 east of Mine Centre (MC-9).

near Highway 11 east of Mine Centre; it is the conglomerate unit at the lowermost part of the sequence, and contains no sandstone interbeds. Unit 2 overlies Unit 1 and consists of beds of massive conglomerate separated by 1-3 m thick beds of massive sandstone. Near the fire tower on the Shoal Lake Road, the conglomerate unit lies nonconformably on the Bad Vermillion Lake Pluton. The unit is deformed and many of the less competent clasts have been extremely stretched as shown in Figure 3.3.

Units 1 and 2 grade eastward along the belt into a volcanic pebble-rich conglomerate with sandstone interbeds. Interbeds are relatively common, averaging 1-2 meters in thickness and containing parallel laminations. The volcanic pebbles are rounded and usually felsic to intermediate in composition. Wood (1980) reported that framework clast sizes decrease stratigraphically upward. The present study confirms this as a generality but not a rule.

Unit 5, a clast-supported polymict conglomerate, overlies the feldspathic sandstone on Neil Point and pinches out gradually to the west. The polymict orthoconglomerate is generally less deformed than to the east near Shoal Lake in Ontario (Units 1 and 2), especially at the major area of exposure which is on the southern part of Neil Point (see Plate 1). The clasts are generally

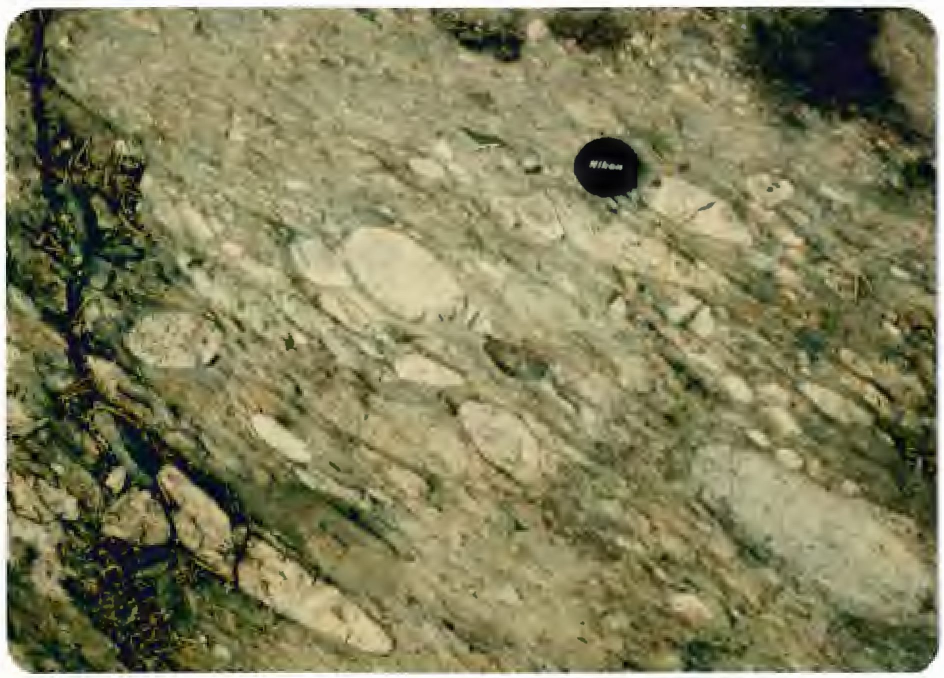

Figure 3.3 Unit 2 of the Seine Group conglomerate in the eastern part of the study area with a volcanic sandstone interbed near the top of the photograph. Note the orientations of deformed clasts that resemble imbrication. Bedding is parallel to the top of the photograph.

stretched only slightly; some may be oval-shaped as a result of minor deformation. The conglomerate is also present as a narrow belt extending from Tilson Bay to Jackfish Bay (see Plate 1). The thin belt west of Neil Point is more deformed than the thick unit on Neil Point and at first glance, seemed to be matrix-supported. However, a closer analysis revealed that it is clast-supported, with many of the least competent clasts having been stretched and sheared into matrix. The polymict clast-supported unit shows crude massive bedding. Above many conglomerate beds is a pebbly sand interbed. Megascopic modal analysis shows an increase of granite cobbles and a decrease of gabbroic and mafic volcanic cobbles relative to the eastern conglomerate. The sandstone interbeds that occur locally in Unit 5 exhibit no cross-bedding or sedimentary structures other than horizontal bedding. The unit is overlain by fault-related rocks such as mylonite. Figure 3.4 is a measured section obtained on the southeast part of Neil Point at locations RL-57 through RL-65 (see Plate 1). The conglomerate there displays very crude bedding, little imbrication, and consists of well-rounded boulders, cobbles, and pebbles. The framework grain size decreases upward in the column throughout the western area.

Poulsen (1984) noted a broad upsection transition from

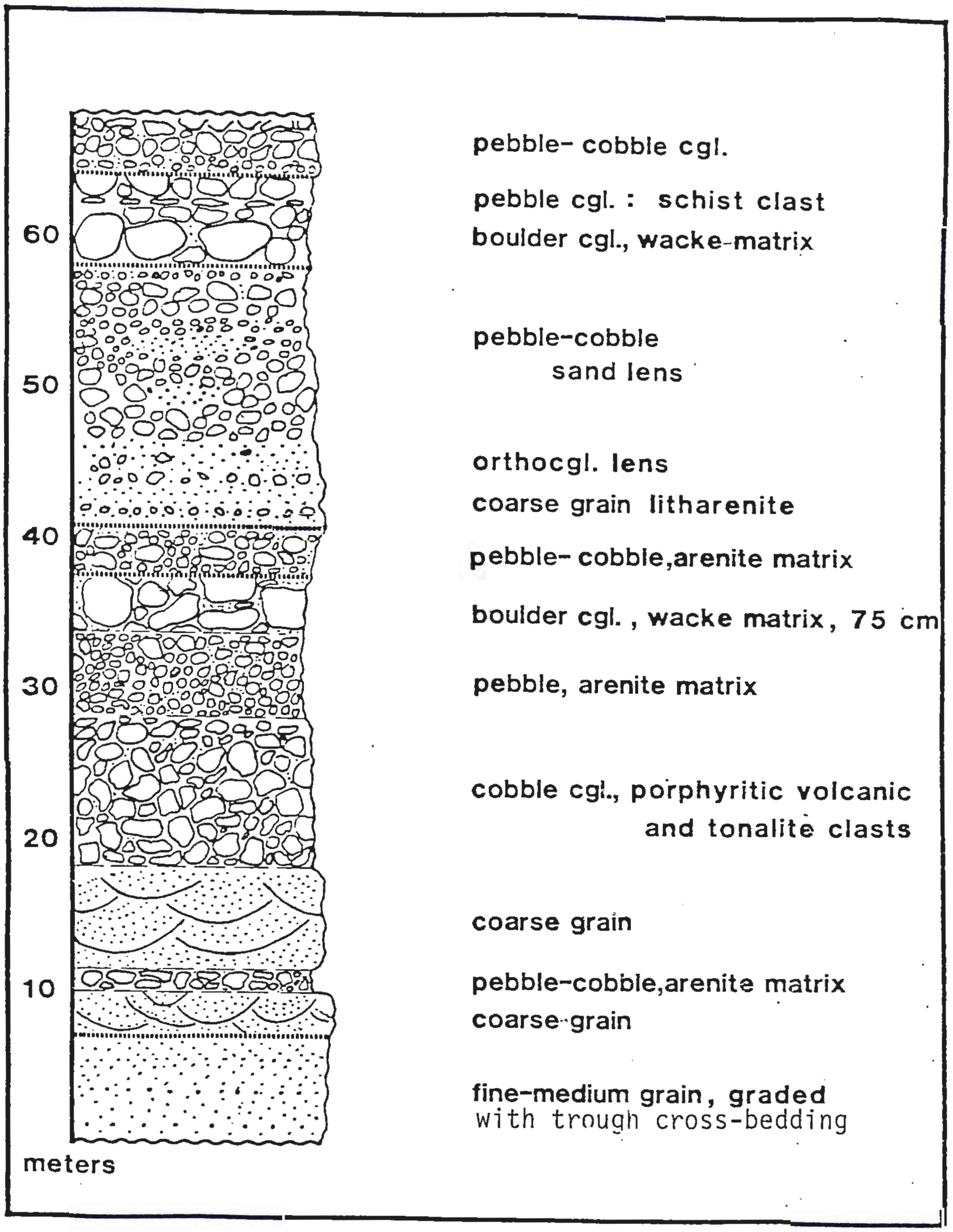

Figure 3.4 Measured section of Seine Group conglomerate (Unit 5) on Neil Point at locations RL59-RL62.

poorly sorted conglomerate to sorted conglomerate with sandstone interbeds to pebbly sandstone to trough cross-bedded sandstone in the Mine Centre area. This interpretation is not supported in the western part of the study area where the conglomerate is present as the uppermost unit above the sandstone.

Megascopic modal analyses shows that volcanic cobbles and pebbles are the most abundant clast (see Figure 3.5); they are usually of felsic to intermediate compositions. Identification of volcanic clasts on the outcrop was based on texture and color. Tonalitic intrusive clasts, as shown in Figure 3.6, are nearly as abundant. In Figure 3.7 are histograms showing the results for Units 1 and 2 and Unit 5. The high matrix values are partially accounted for by having named any grain less than 1 cm in diameter as "conglomerate-matrix". In the eastern part of the study area, Units 1 and 2 have higher "conglomerate-matrix" values, partly as a result of the deformed nature of the conglomerate.

Field Description, Feldspathic Sandstone Units 3 and 4

Unit 3 consists of deformed feldspathic sandstone that overlies Units 1 and 2 in the eastern part of the study area, as on the northeast shore of Shoal Lake. Unit 3 includes the deformed schistose feldspathic sandstone

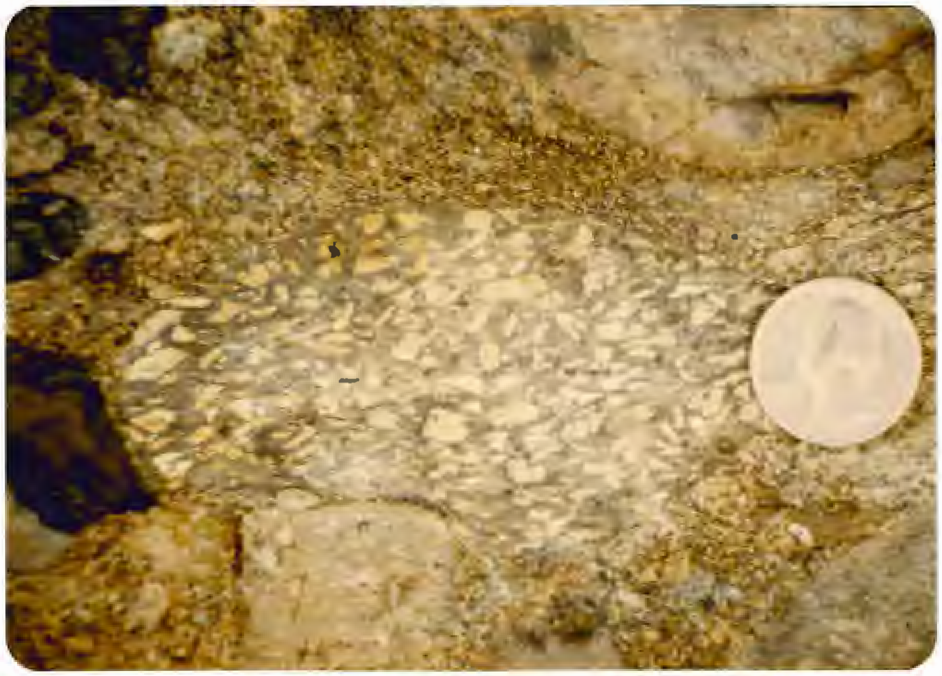

Figure 3.5 Porphyritic volcanic cobble within a sandy matrix in the orthoconglomerate located on Neil Point.

Figure 3.6 Well-rounded feldspar porphyry cobble within a muddy wacke matrix of the orthoconglomerate located at RL62 on Neil Point.

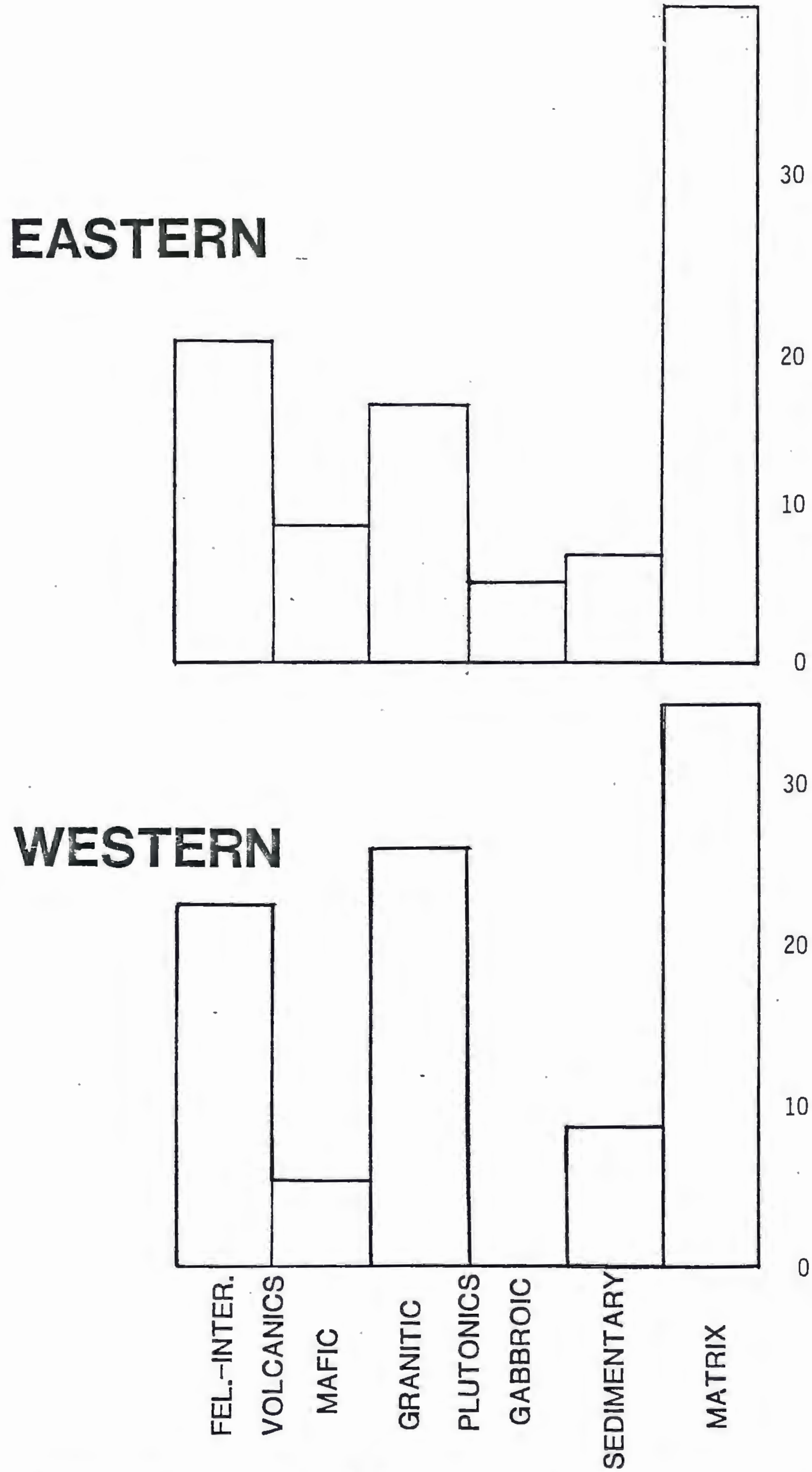

Figure 3.7 Histograms of Seine conglomerate showing results of the megascopic modal analysis of Units 1 and 2 of the eastern area and Unit 5 of the western area.

present south of the Seine River and Wild Potato Lake. In hand sample the feldspathic sandstone is grey to brown, sheared muscovite-biotite schist made up of fine-grained composite quartz and plagioclase. The unit weathers into brownish slabs, limonite-coated along foliation planes. Figure 3.8 shows Unit 3 where it contains locally deformed quartz and volcanic pebbles. Stratigraphically higher in the unit there is an increase in the percentage of muscovite and biotite, due to a higher original mud content. This unit can be distinguished from the biotite schists of the area by thin section analysis and in the field, usually, by a lighter color. This unit grades upward into fine-grained silty, schistose metasediments. Despite the sheared and schistose nature of these units, original sedimentary structures are exhibited, including measureable cross-bedding, of both trough and planar types. Near the very top of Unit 3 the sheared sandstone and siltstone grade upward into siliceous magnetic iron-formation. The banded iron-formation is a thin unit, approximately 15 meters thick; exact determination of thickness is difficult due to the lack of exposure. Laminae are made up of finer laminae between 1 and 5 mm thick. The banded iron-formation contains polycrystalline quartz, pyrite, pyrrhotite, chlorite, biotite, and magnetite as shown in Figure 3.9.

Figure 3.8 Outcrop of Unit 3 of the Seine Group feldspathic sandstone in the eastern part of the study area at location MC-36 on the south shore of Shoal Lake where it contains deformed volcanic pebbles and less deformed granitic pebbles.

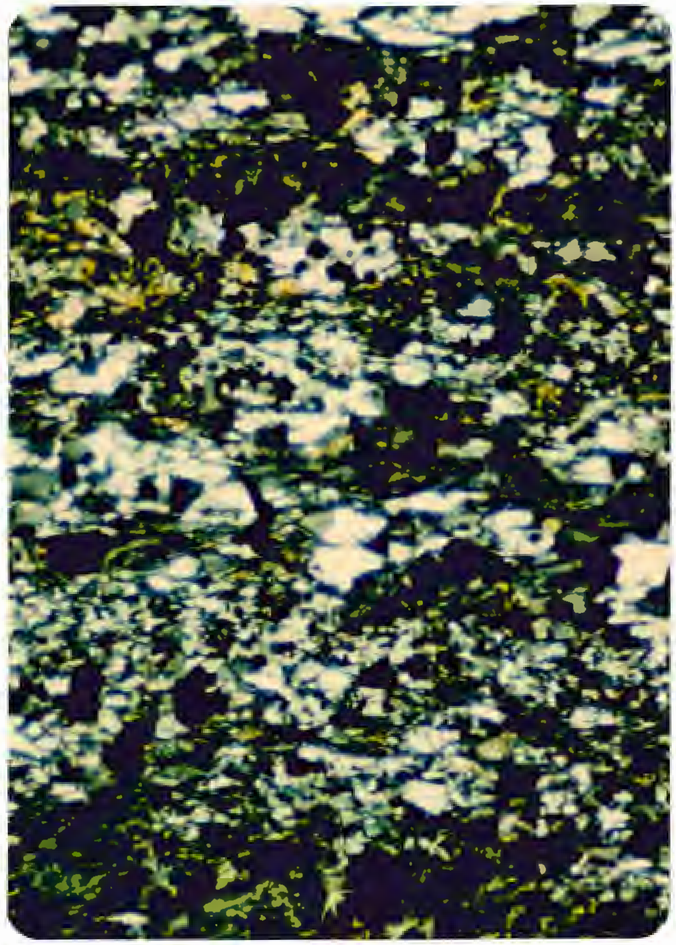

Figure 3.9 Photomicrograph of banded iron-formation present near the top of Unit 3 in the eastern part of the study area south of the Seine River and Wild Potato Lake. Note the quartz, chlorite, biotite, and opaques identified as pyrite, pyrrhotite, and magnetite (field of view=2.4mm long, crossed nicols).

Arkosic unit 4 crops out in three specific areas; west of the road in section 32 and along the road in sections 33 and 34, a thin unit trending east-west between Jackfish and Tilson Bay, and a unit over 900 meters thick on Neil Point, Grindstone, Dryweed and part of Big American Islands. Original sedimentary features such as cross-bedding and graded beds exhibit topping directions to the south. On Dryweed Island, Unit 4 overlies metavolcanic rocks. This contact is interpreted as a fault contact, as a topographically low linear "ditch" extends along the contact across Dryweed Island and many of the other smaller islands. Near the top of Unit 4 on the southern part of Dryweed Island the feldspathic sandstone contains interbedded mica-rich metasediments (originally muds?) and thin beds of magnetic banded iron-formation (as shown in Figure 3.10) consisting of magnetite and meta-chert. Unit 4 is overlain by metavolcanics, interpreted as the Keewatin Group, on the south side of Dryweed Island and Big American Island; the contact is shown in Figure 3.11. The metavolcanics contain extremely contorted laminae with a mylonitic schistose foliation in contact with the arkosic arenite. This contact is also interpreted as a fault contact by other workers (Ojakangas, pers. comm. 1985).

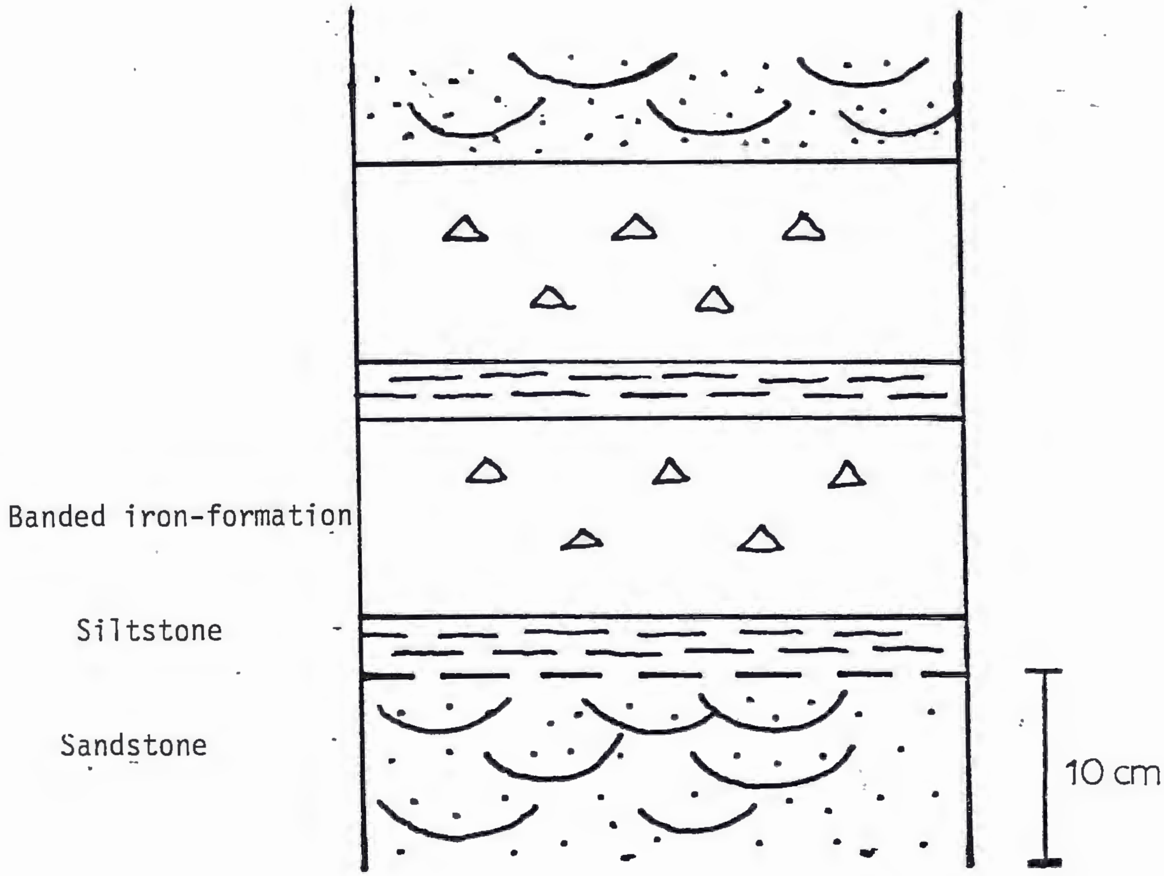

Figure 3.10 Banded iron-formation beds present on the south side of Dryweed Island at location RL265 (vertical field of view=40 cm).

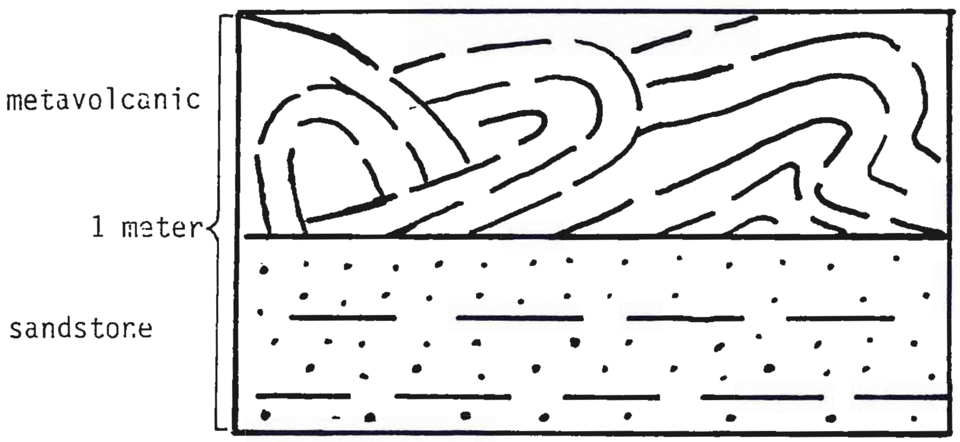

Figure 3.11 Sheared contact of the Seine feldspathic sandstone and the older Keewatin (Archean) metavolcanics on Big American Island.

Paraconglomerate

There is a separate, small but mappable unit consisting of a paraconglomerate in the southwest part of Jackfish Bay. It is present in a sequence of metavolcanics believed to belong to the older Keewatin Group. This unit is a paraconglomerate with abundant quartz pebbles and volcanic cobbles. The unit thus may be older than the Seine Group and older than part of the Keewatin. The paraconglomerate exhibits a dark-green matrix that is highly sheared, suggesting that it was altered by faulting. Its relative stratigraphic position is unknown.

Chapter 4

PETROGRAPHY

Techniques

Megascopic modal analyses on outcrops of the conglomerates were conducted along traverses perpendicular to bedding across weathered surfaces. At most well-exposed outcrops, three lines were drawn across the surface with chalk, each one meter long and spaced 10-20 cm from the other as shown in Figure 4.1. The number of millimeters of each clast type and matrix traversed was recorded. The percent of any particular clast type was then calculated. Pebbles and granules with an average diameter less than one cm were counted as "conglomerate-matrix."

Staining for potassium-feldspar was done using the cobaltinitrate stain for potassium. In the field, ten clasts were stained on two-dimensional outcrop surfaces in the following manner:

1. Surface was cleaned with stiff brush.
2. A "Playdoh" dam was constructed (see Figure 4.2).
3. Hydrofluoric acid was poured into the dam and allowed to stand at least 15-20 seconds.
4. The dam was broken and the surface washed with water.
5. Dam was rebuilt.
6. A saturated solution of sodium cobaltinitrate was poured into the dam and allowed to stand for one minute.
7. The dam was broken again and surface washed with water.
8. The yellow stained portion was estimated using percentage charts (after Compton, 1962).

Figure 4.1 Megascopic modal analyses of the Seine Group conglomerate in the eastern part of the study area at location MC122 east of Mine Centre. Moss was peeled from the outcrop and then it was treated with Hilex bleach and a scrub brush.

Figure 4.2 Tonalite clast stained for alkali feldspar at the outcrop using a "Playdoh" dam. This sample, at location RL102, averages 2 percent alkali feldspar.

Thin section heels were stained in the lab for alkali feldspar (yellow) and for plagioclase (red) using hydrofluoric acid and BaCl as reagents. Cobaltinitrate and Amarand Red were the stains used.

Thin sections of 121 samples were studied in detail. Eleven thin sections of the least deformed sandstone and four thin sections of conglomerate-matrix were point-counted with six random traverses of one hundred points each made across each slide. Grains with a diameter of less than 0.04 mm were considered as matrix. A total of 21 thin sections were point-counted.

Three samples of sandstone were disaggregated using mortar and pestle and then sieved with a 250 micron sieve. Heavy minerals were separated from the less than 250 micron sample using tetrabromoethane. The heavy minerals were divided into magnetic and nonmagnetic fractions. The nonmagnetic heavy minerals were then mounted for microscopic study.

Operational Definitions

The following grain definitions were used in this study-

Common quartz grains:

1) single crystal detrital quartz grains, usually slightly undulose, (see Figure 4.3) and
2) semicomposite quartz grains with at least 50% of

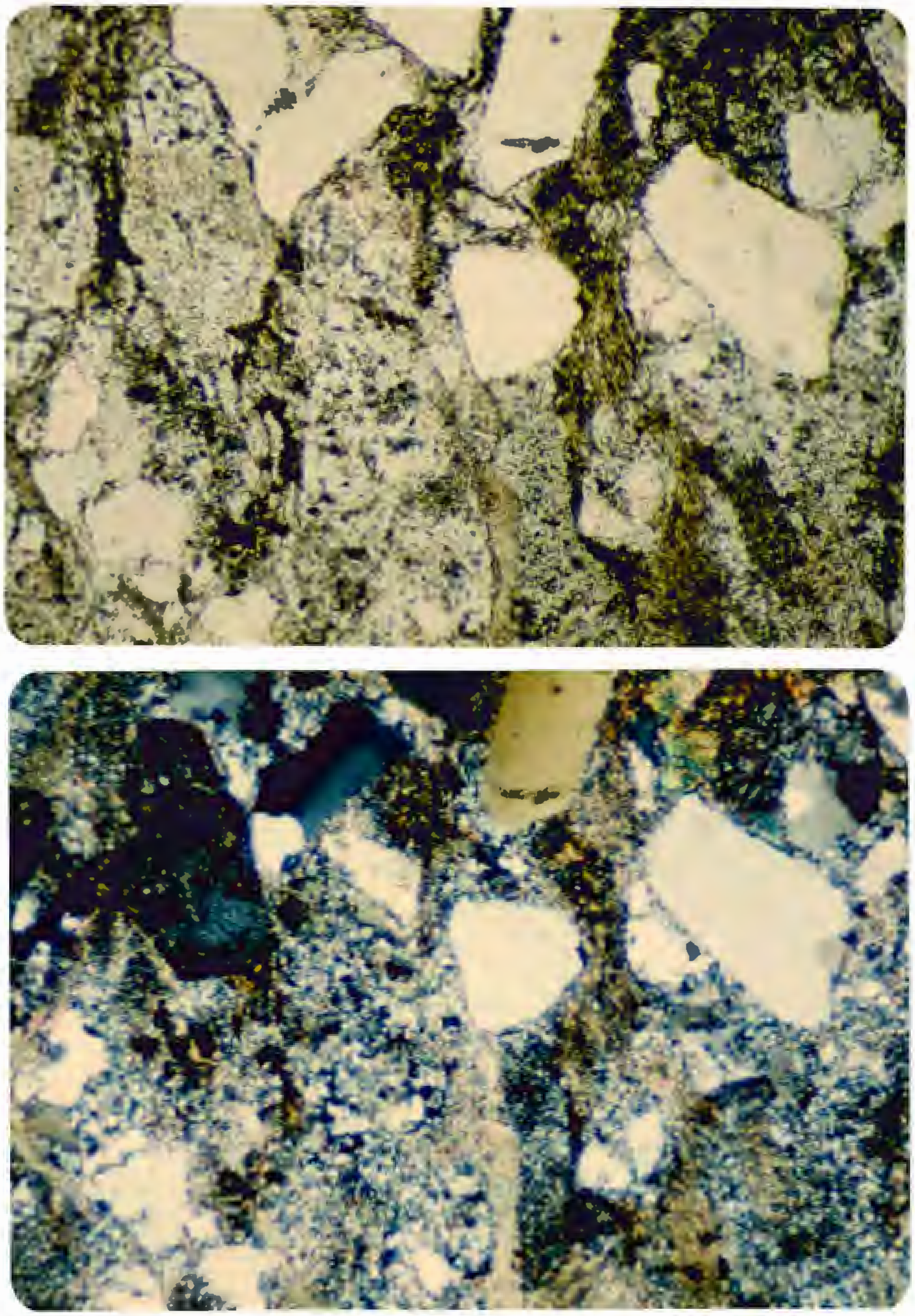

Figure 4.3 Photomicrograph of Seine Group feldspathic sandstone exhibiting subangular common quartz grains and subrounded felsic volcanic rock fragments (field of view=2.4 mm wide, (A) is uncrossed nicols, (B) is crossed nicols).

the area as one single crystal.

Polycrystalline Quartz grains:

1) composite quartz grains consisting of two or more crystals and having no single crystal comprising more than 50% of the grain; most consist of more than six crystals

2) typically show weakly sutured boundaries

Chert grains:

1) is also a polycrystalline quartz with individual crystals being microscopic; sugary in hand sample

Plagioclase grains:

1) single crystal detrital grains, often twinned, (see Figure 4.4) usually showing slight alteration (sericitization) of less than 10% of the grain

2) usually identified as albite using Michel-Levy method

Altered Plagioclase grains:

1) same as plagioclase above, but with more than 10% of the grain altered

Orthoclase grains:

1) single crystal grains, stain yellow with cobaltinitrite, not twinned

Felsic-Intermediate Volcanic Rock Fragments:

1) grains made up of a plagioclase-quartz volcanic groundmass, commonly porphyritic, fine-grained

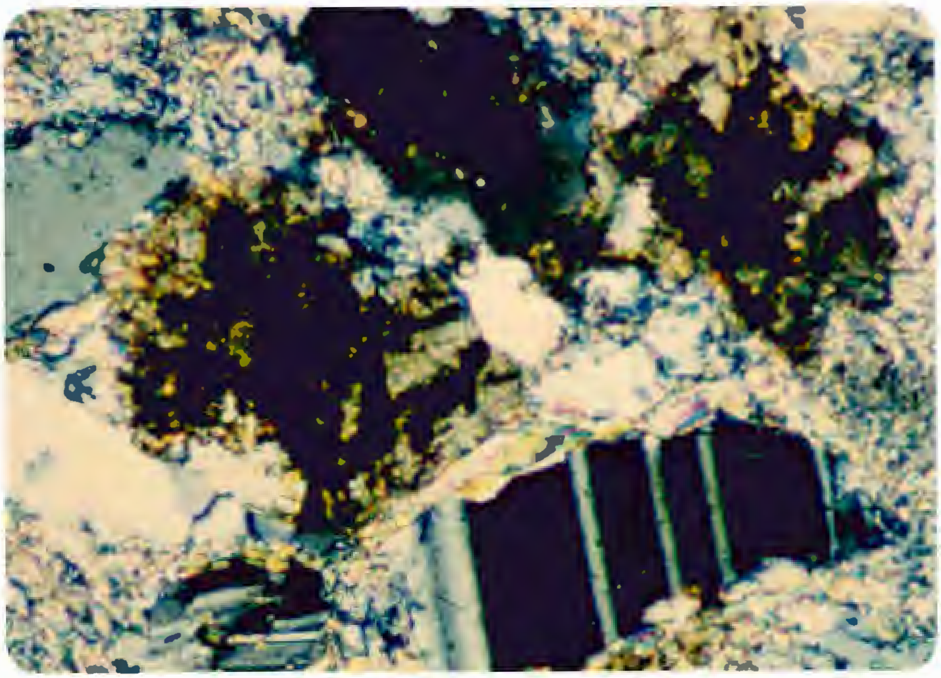

Figure 4.4 Photomicrograph of Seine Group feldspathic sandstone showing subangular twinned plagioclase grain, iron carbonate fragments, and micaceous matrix (field of view=2.4 mm wide, crossed nicols).

equidimensional or nearly so, and

2) may exhibit flow-banding or other volcanic features

Mafic Volcanic Rock Fragments:

1) grains of volcanic rock fragments as above with elongate plagioclase grains present throughout or

2) greenschist grade metavolcanic rocks (see Figure 4.5)

Matrix:

1) silt-and clay-sized components of quartz, plagioclase, and sericite with minor epidote and limonite

Accessory Minerals:

1) Opaques including irregular shaped pyrite, magnetite,limonite, and hematite

2) Chlorite as flakes and irregular shaped grains

3) Biotite as irregular shaped flakes

4) Iron carbonate with or without quartz fragments (see Figure 4.4)

Petrography of the Conglomerate Clasts

The clast-supported conglomerates of Minnesota and Ontario contain pebbles, cobbles, and boulders of tonalitic and gabbroic intrusive rocks, felsic to mafic volcanics, metachert, biotite schist, arkosic arenite, quartz, and iron-formation. The clasts are generally rounded to well-

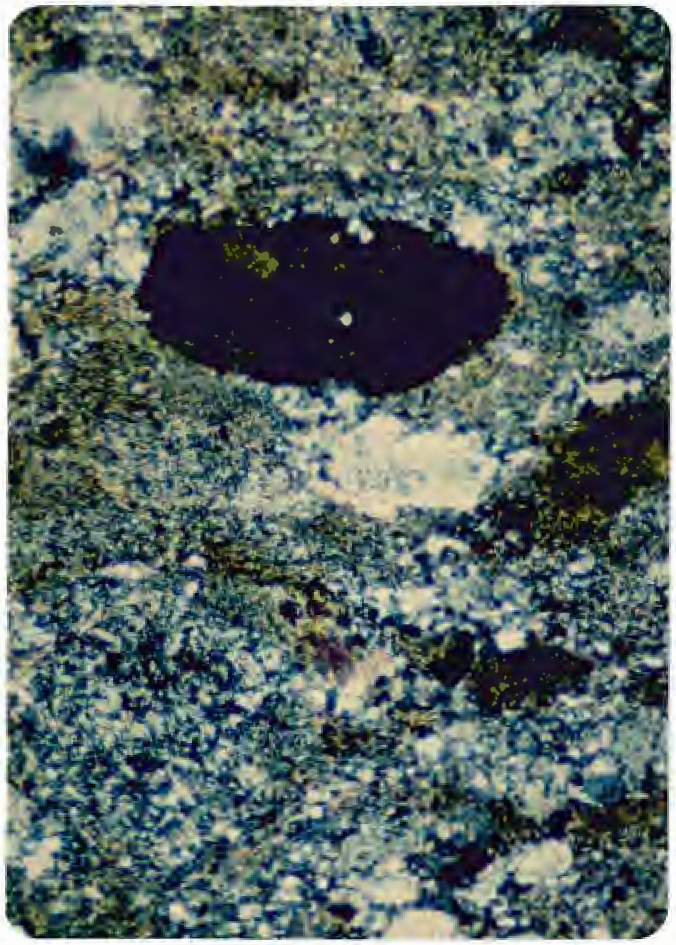

Figure 4.5 Photomicrograph of "conglomerate-matrix" exhibiting metamorphosed greenstone(?) fragment (dark), and other volcanic rock fragments, from sample MC53c located near the Shoal Lake Road (field of view=2.4 mm long, crossed nicols).

rounded and moderately sorted. It is difficult to distinguish pebbles from matrix of the same color. The most abundant clasts are volcanic rocks, as reported by Wood (1980), which range from rhyolite to andesite. Second in abundance are granitoid rocks which include alkaline granite to quartz diorite, and gabbroic anorthosite. Cross-cutting veins have developed in extensional fractures of the less deformed granitic clasts as shown in Figure 4.6; quartz is the major constituent of the veins. It is likely that grey, columnar-shaped crystals grew in pace with dilation of fractures because some grains show crystallographic continuity across the vein.

The metavolcanic rocks are aphanitic or porphyritic with quartz or feldspar phenocrysts. The groundmass is made up of fine-grained quartz and feldspar as shown in Figure 4.7. The feldspar is almost entirely plagioclase. Staining of thin section heels has revealed less than 4% alkali feldspar, and much of the plagioclase is of a sodic type. Intermediate and mafic volcanic clasts consist of long slender plagioclase laths averaging 0.1-3 mm long with fine-grained quartz and very fine-grained sericite. Minor carbonate is present. The more mafic volcanic clasts consist of a chlorite-rich greenschist, commonly with quartz amygdules. Some metavolcanic pebbles contain abundant epidote, possibly a result of a basalt that has

Figure 4.6 Fractured tonalite cobble exhibiting fractures offset in a direction approximately perpendicular to foliation, at location RL62 on Neil Point.

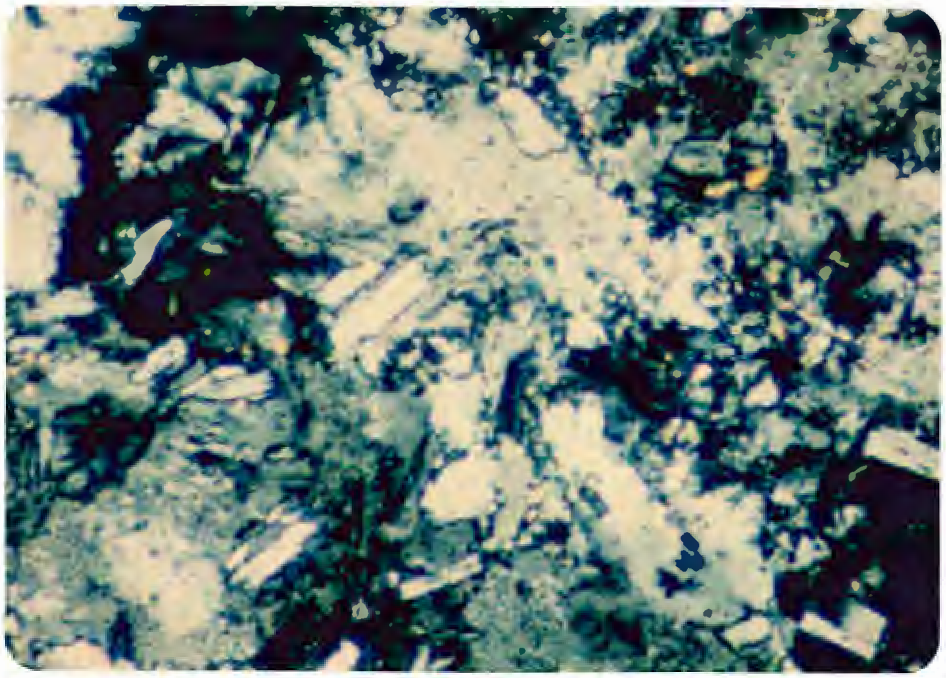

Figure 4.7 Photomicrograph of aphanatic felsic volcanic cobble in the conglomerate at location RL117 on Neil Point (field of view=0.5 mm wide, crossed nicols).

experienced metamorphic events (see Figure 4.5).

Plutonic clasts are mostly cobble-to boulder-sized and well rounded. Most are tonalitic, consisting of coarse-grained quartz and plagioclase; chlorite is interpreted to be altered hornblende. The plagioclase is altered to sericite and minor epidote. Five thin section analyses of plutonic clasts all plot in the tonalitic field on the classification chart shown in Figure 4.8. Goldich and Peterman (1980) showed that modal analyses of the metamorphosed granitoids, Lawson's Laurentian, plot in the tonalitic field while the unmetamorphosed plutonic rocks (Lawson's Algoman), plot in the granodiorite or quartz-monzonite fields. Modal analyses of thin sections of the granitic clasts as shown in Table 4.1 yield an average composition of 57% plagioclase, 33% quartz, 2% biotite, and 1% alkali feldspar. Staining of heels and of ten granitic clasts on two-dimensional outcrop faces yielded less than 5% alkali feldspar in all samples. Gabbroic clasts consist of quartz, plagioclase, and hornblende with fine-grained calcite, quartz, and epidote.

Metamorphosed chert cobbles, (Figure 4.9), are commonly white with a sugary texture. In thin sections, a coarser-grained texture is notable, and minor sericite is disseminated throughout the clasts.

Minor sandstone cobbles are not believed to be

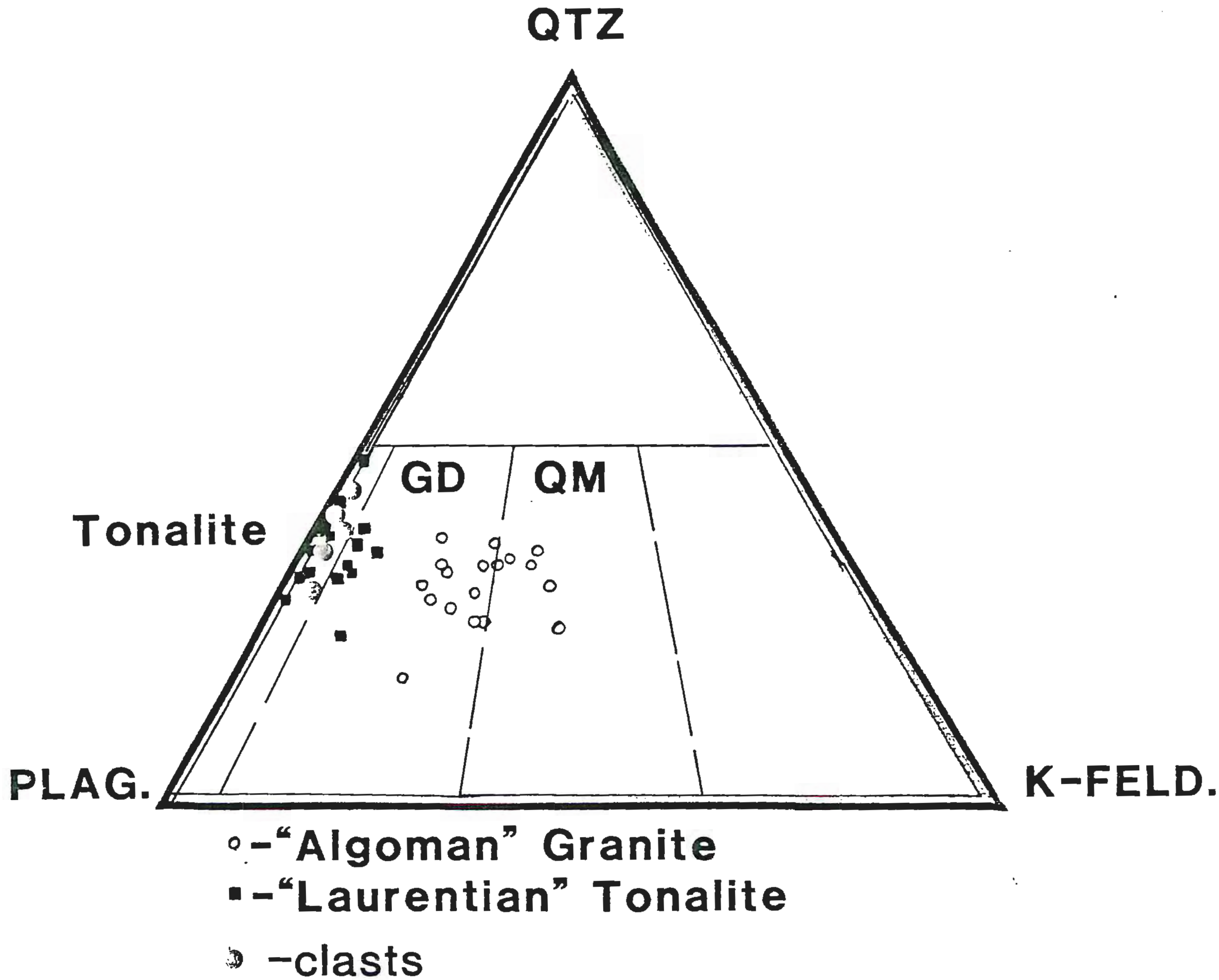

Figure 4.8 Modal analyses of plutonic rocks of the Rainy Lake area including the clasts of the Seine Group Conglomerate (QM is the quartz monzonite field and GD is the granodiorite field; After Goldich and Peterman, 1980).

Sample	MC5	MC114	MC118	RL102	RL102B
Quartz	31.0	26.0	39.0	36.0	32.0
Feldspar					
Plagioclase	61.5	56.5	49.0	55.0	61.0
Alkali Feldspar	2.5	0	2.0	1.5	0
Total Feldspar	64.0	56.5	51.0	56.5	61.0
Carbonate	3.0	4.5	8.0	4.0	3.0
Biotite	2.0	0	1.0	1.5	2.5
Chlorite	0	12.0	1.5	3.0	2.0
Opaques					
Iron carbonate	0	0	0	0	0
Pyrite	0	1.0	0	0.5	0
Magnetite	0	0	0	0	0

Table 4.1 Thin section modal analyses of tonalitic pluton and tonalite clasts within the Seine conglomerate. Sample MC5 is of the Bad Vermillion Lake intrusive while MC114 and MC118 are clasts from Unit 2 in the Mine Centre area. Samples RL102 and RL102B are clasts from Unit 6 on Neil Point.

Figure 4.9 Meta-chert cobble in the Seine Conglomerate located at RL62 on Neil Point.

intraformational, although they show a composition of quartz, plagioclase and rock fragments, nearly the same as the feldspathic sandstone. Figure 4.10 shows a metamorphosed sandstone granule in the conglomerate matrix. Sericite in the granule is preferentially oriented in two directions, and neither is parallel with the foliation of the conglomerate itself further suggesting an older sandstone source.

Biotite schist clasts are present but rare. These clasts are made up of biotite, quartz, and plagioclase (see Figure 4.11), and porphyroblasts of staurolite are present in a few clasts. The clasts have a different internal foliation orientation relative to surrounding matrix and clasts, suggesting derivation from an older metamorphosed source. The quartz grains within the schist are rarely undulose. No rock fragments, as in the feldspathic sandstone, are observable.

Coarse-grained carbonate-rich pebbles are made up of carbonate, quartz, and hematite or pyrite. These pebbles and granules are interpreted as altered volcanic rocks. Carbonate and hematite or pyrite have probably replaced ankerite or siderite. Siliceous magnetic iron-formation cobbles are present, particularly in the eastern part of the study area. The iron-formation is banded and is the so-called "Algoman" type.

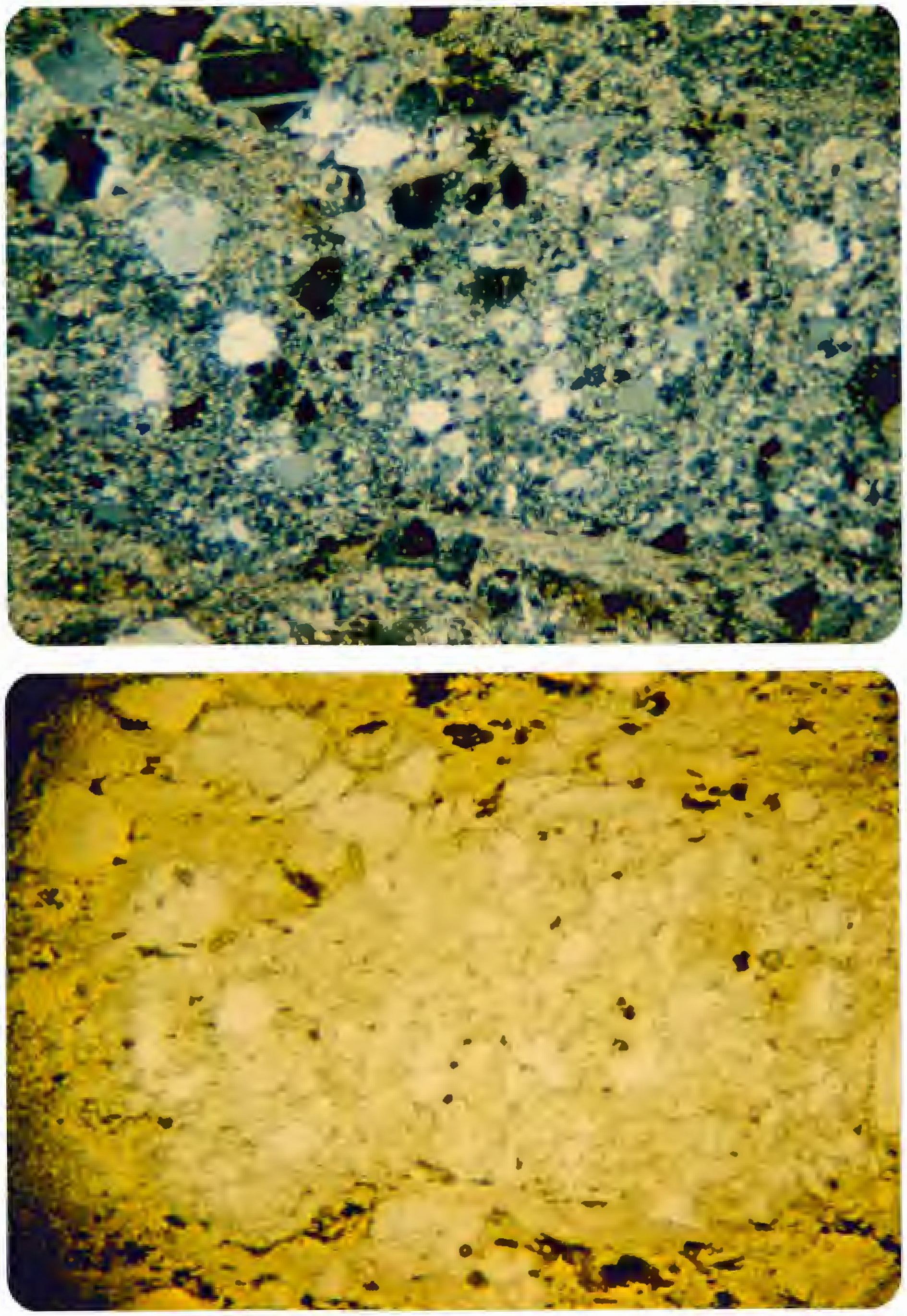

Figure 4.10 Photomicrograph of the Seine Group Conglomerate exhibiting a granule of feldspathic sandstone identical to the Seine Group sandstone (field of view=5 mm wide, (A) is crossed nicols, (B) is uncrossed nicols).

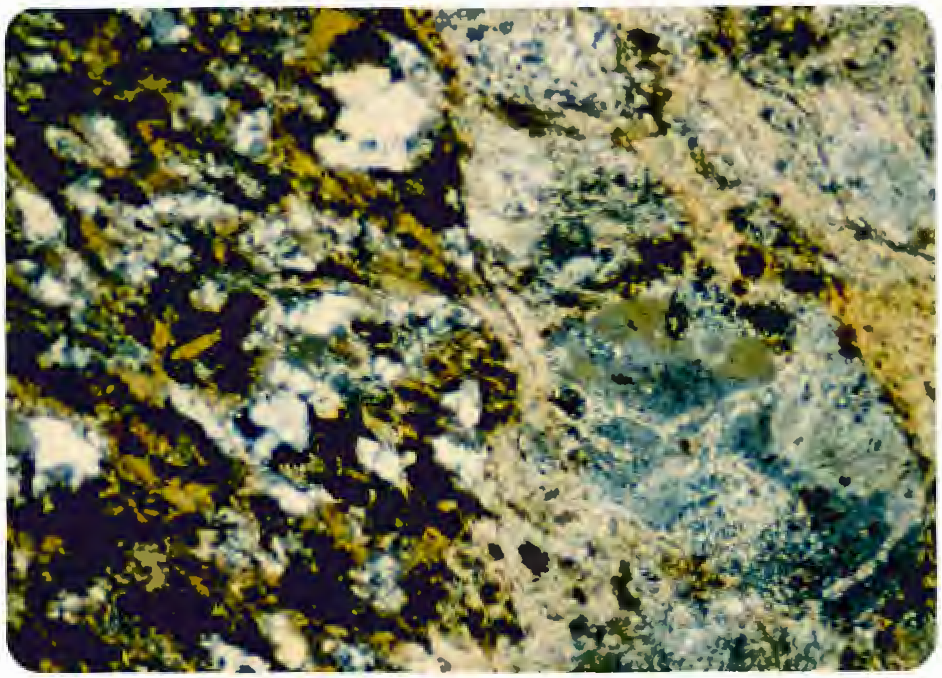

Figure 4.11 Photomicrograph of a biotite schist pebble in the Seine Group conglomerate (pebble on left side of photo, field of view= 5.0 mm wide, crossed nicols).

Petrography of the Conglomerate Matrices and Interbeds

The "conglomerate-matrix" is made up of angular, fine to coarse sand and granules of volcanic rock fragments, intrusive rock fragments, plagioclase, volcanic quartz, and chert, set in a fine matrix of biotite, muscovite, chlorite, quartz, feldspar, hematite, and pyrite. In hand sample the conglomerate-matrix is poorly sorted, green on fresh surfaces, and exhibits a strong schistosity. Many volcanic rock fragments are porphyritic with euhedral plagioclase and quartz phenocrysts, some with prominent embayments. Laths of plagioclase are set in a finely crystalline matrix. Feldspars have euhedral crystal outlines, and some have well-defined zoning.

Modal analyses of three thin sections of the conglomerate-matrix (the fraction dominantly less than 4 mm) yield an average composition of 53% rock fragments (44% felsic to intermediate volcanics), 12% feldspar, 13% quartz, with 16% fine-grained quartz-feldspar-mica matrix (less than 0.05 mm) as shown in Table 4.2. Carbonate-rich grains containing quartz are also present.

The "conglomerate-matrix" contains common quartz grains and fine-to medium-sized, polycrystalline composite quartz grains having straight polygonized crystal contacts. These grains are elongated in the foliation plane. Many quartz

Sample	MC53C	MC19	RL14A	RL60
Quartz				
Common Quartz	1.3	6.8	3.0	13.6
Polycrystalline Quartz	5.6	14.4	6.7	2.0
Volcanic Quartz		1.0	0.3	1.3
Total Quartz	6.9	22.2	10.0	16.9
Feldspar				
Plagioclase, Fresh	1.7	0.2	7.0	1.0
Plagioclase, Altered	8.0	12.3	5.8	12.5
Alkali Feldspar			0.7	
Total Feldspar	9.7	12.5	13.5	13.5
Rock Fragments				
Volcanic, Felsic-Intermediate	36.2	22.7	43.6	26.3
Volcanic, Mafic	7.0	3.5	4.0	0.7
Greenschist				
Plutonic (Quartz-Plagioclase)	11.3	10.8	3.0	8.3
Schist (Biotite)	4.3			1.0
Sandstone (Feldspathic)		0.5		0.2
Chert	2.5	5.2	3.0	1.2
Carbonate/Quartz	2.7	1.3	7.0	7.5
Other	0.7			0.3
Total Rock Fragments	57.2	42.5	60.6	45.0
Muscovite	0.2	0.3	0.5	
Biotite	1.7	0.5	0.3	2.2
Epidote				
Chlorite		2.7	0.2	
Opaques				
Limonite	0.2			0.3
Hematite		0.3	4.5	0.8
Iron Carbonate				
Pyrite	0.8			0.3
Magnetite			0.2	
Matrix				
Matrix Mica	11.7	8.3	11.7	12.7
Matrix Quartz-Feldspar	3.2	8.0	6.2	7.3
Total Matrix	14.9	16.6	17.9	20.0

Table 4.2 Modal analyses of thin sections of Seine Group "conglomerate-matrix" and volcanic sandstone interbeds. Samples MC19 and MC53C are "conglomerate-matrix" from the eastern part of the study area, RL14A is "conglomerate-matrix" from Neil Point, and RL60 is a volcanic arenite interbed.

grains exhibit semicomposite extinction and also contain muscovite microlites. The polycrystalline composite grains may not have been polycrystalline at the time of deposition in the Seine Group and therefore may not represent a detrital metamorphic origin. These grains are usually made up of less than 10 subcrystals. Pettijohn and others (1973) state that grains made up of less than 10 subcrystals may not be of metamorphic origin.

Cobaltinitrate staining of "conglomerate-matrix" thin section heels yields an average of 4% alkali feldspar. Calcium-bearing plagioclase, stained using Amarand, averages 16% throughout the conglomerate-matrix and varies due to the variety of lithologies represented as rock fragments.

In hand sample the sandstone interbeds are buff to tan-brown and poorly sorted; thin section modal analyses yield 15% quartz, 13% feldspar, and 50% rock fragments, mostly felsic-intermediate volcanics.

Petrography of the Feldspathic Sandstone

In hand sample the tan-brown, locally grey, medium- to coarse-grained feldspathic sandstone is moderately to poorly sorted and subrounded (Figure 4.12). Modal analyses of thin-sections of the unit are shown in Tables 4.3a, b, and c. The modal analyses plot in the arkosic arenite

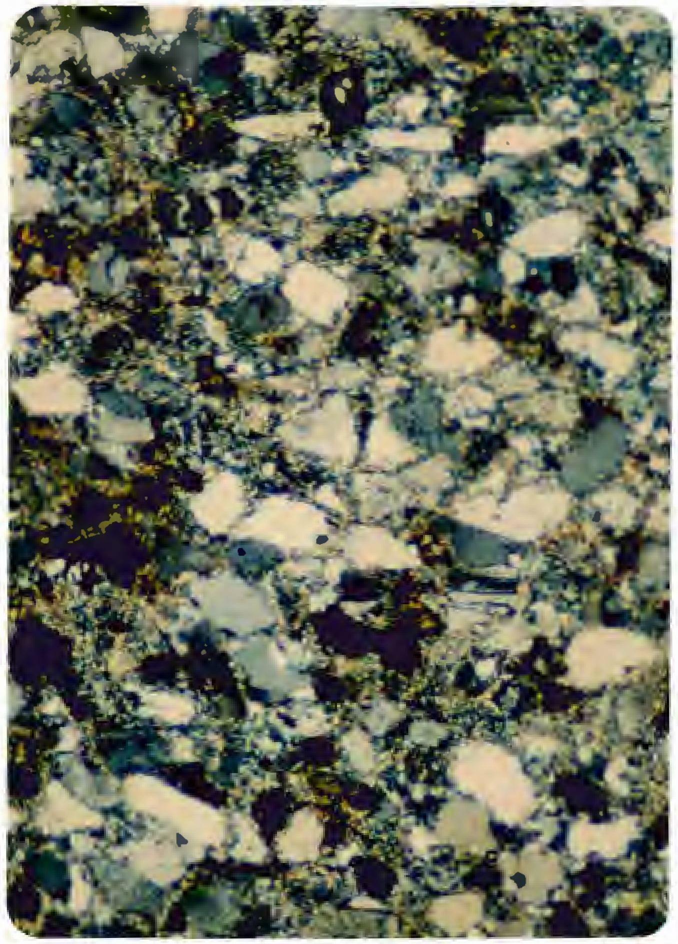

Figure 4.12 Photomicrograph of the Seine Group feldspathic sandstone, Unit 4, located in the western part of the study area (field of view=2.4 mm high, crossed nicols).

Sample	RL17	RL56A	RL57	RL63
Quartz				
Common Quartz	30.3	27.3	37.8	31.3
Polycrystalline Quartz	13.7	16.8	7.5	16.7
Volcanic Quartz			0.2	0.3
Total Quartz	44.0	44.1	45.5	48.3
Feldspar				
Plagioclase, Fresh	5.0	9.5	6.2	8.9
Plagioclase, Altered	6.5	4.2	10.2	5.7
Alkali Feldspar	0.3			
Total Feldspar	14.5	13.7	16.4	14.6
Rock Fragments				
Volcanic, Felsic-Intermediate	6.5	8.3	6.0	5.2
Volcanic, Mafic	0.2		0.8	0.2
Greenschist				0.2
Plutonic (Quartz-Plagioclase)	9.3	7.7	6.0	5.5
Schist (Biotite)				
Chert	2.0	0.8	1.0	1.2
Sandstone (Feldspathic)				
Carbonate/Quartz				
Other	0.3		0.2	
Total Rock Fragments	18.3	16.8	14.0	12.1
Muscovite		0.3	0.2	
Biotite			0.3	0.2
Epidote	3.0	0.7	0.3	0.2
Chlorite	0.5	0.7	0.7	
Opaques				
Limonite			0.2	0.3
Hematite		3.2	1.9	0.3
Iron Carbonate	1.7	1.3	1.2	3.0
Pyrite	0.2			
Magnetite			1.0	0.4
Apatite			0.2	
Matrix				
Matrix Mica	10.2	9.4	9.5	13.0
Matrix Quartz-Feldspar	6.5	4.0	8.5	7.2
Total Matrix	16.7	13.4	18.0	20.2

Table 4.3a Modal analyses of thin sections of Seine Group feldspathic sandstone Unit 4 in the western part of the study area.

Sample	RL79	RL27	RL10B	IF80
Quartz				
Common Quartz	16.5	23.7	30.3	21.5
Polycrystalline Quartz	33.3	31.5	18.7	21.8
Volcanic Quartz			0.7	
Total Quartz	49.8	55.2	49.7	43.3
Feldspar				
Plagioclase, Fresh	4.8	9.0	16.0	17.0
Plagioclase, Altered	1.8	1.0		3.5
Alkali Feldspar			1.5	
Total Feldspar	6.6	10.0	17.5	20.5
Rock Fragments				
Volcanic, Felsic-Intermediate	7.8	8.0	1.8	5.5
Volcanic, Mafic			0.5	
Greenschist	0.3		0.2	
Plutonic (Quartz-Plagioclase)	8.5	8.9	6.0	6.3
Schist (Biotite)				
Chert	2.0	2.0	3.0	1.7
Sandstone (Feldspathic)				
Carbonate/quartz				
Other	0.7			
Total Rock Fragments	18.3	18.9	11.5	13.1
Muscovite	0.8	0.2	0.3	0.2
Biotite	1.2	3.5	5.5	
Epidote	3.5	0.5		0.2
Chlorite	5.8	0.7	1.5	0.2
Opaques				
Limonite				
Hematite	1.3	0.6	0.7	1.0
Iron carbonate				3.0
Pyrite		0.3		1.0
Apatite	0.2			
Magnetite	0.2	0.2		
Matrix				
Matrix Mica	2.5	6.2	8.8	12.3
Matrix Quartz-Feldspar	8.3	4.6	8.8	5.3
Total Matrix	10.8	10.8	17.6	17.6

Table 4.3b Modal analyses of thin sections of Seine Group feldspathic sandstone Unit 4 in the western part of the study area.

Sample	IF256	IF670	RL14A2
Quartz			
Common Quartz	22.0	30.8	42
Polycrystalline Quartz	31.5	16.3	4
Volcanic Quartz			
Total Quartz	53.5	47.1	46
Feldspar			
Plagioclase, Fresh	5.0	6.7	20
Plagioclase, Altered	4.2	7.7	
Alkali Feldspar			
Total Feldspar	9.2	14.4	20
Rock Fragments			
Volcanic, Felsic-Intermediate	6.9	5.6	5
Volcanic, Mafic	0.5		3
Greenschist	0.2		
Plutonic (Quartz-Plagioclase)	4.8	1.3	2
Schist (Biotite)			
Chert	1.5		2
Sandstone (Feldspathic)			
Carbonate/quartz			
Other			
Total Rock Fragments	13.9	6.9	12
Muscovite	2.3		
Biotite	0.5	4.2	3
Epidote	0.2		
Chlorite	0.5		
Opaques			
Limonite		0.3	
Hematite	2.0	0.3	
Iron carbonate	2.7		
Pyrite			
Magnetite	0.3		
Matrix			
Matrix Mica	6.8	15.0	10
Matrix Quartz-Feldspar	7.5	8.5	11
Total Matrix	13.3	23.5	21

Table 4.3c Modal analyses of thin sections of Seine Group feldspathic sandstone Unit 4 in the western part of the study area. IF256 and IF670 are samples of sandstone, RL14A2 is a sandstone pebble within the Seine conglomerate.

field using the sandstone classification scheme of Pettijohn and others (1973) after Dott (1964) shown in Figure 4.13. Note that the plot is near the litharenite field. The feldspathic sandstone averages approximately 50% total quartz. Some of the sandstone samples actually classify as arkosic wackes because of the high matrix contents. The composite quartz grains are not necessarily the "recrystallized metamorphic" quartz type of Krynine (1940), but may be due to cataclasis.

Cobaltinitrate staining shows an average of less than 2% alkali feldspar while Amarand shows approximately 17% plagioclase, usually quite sodic. Plagioclase feldspars can be readily distinguished from quartz in thin section, because of the darker appearance of the feldspars caused by sericitization, and also twinning. Some feldspars are extremely altered whereas others are largely unaffected. Minor plagioclase feldspar is replaced by calcite. A range of feldspar compositions occur in the same rock, emphasizing its detrital origin. Modal analyses yield an average of 50% quartz and 15% plagioclase (excluding the plagioclase present in volcanic and plutonic rock fragments). Rock fragment grains, mostly volcanic, average 18% of the framework grains. Micaceous quartz-feldspar, fine-grained crystalline matrix averages 15%.

The feldspathic sandstone of the eastern part of the

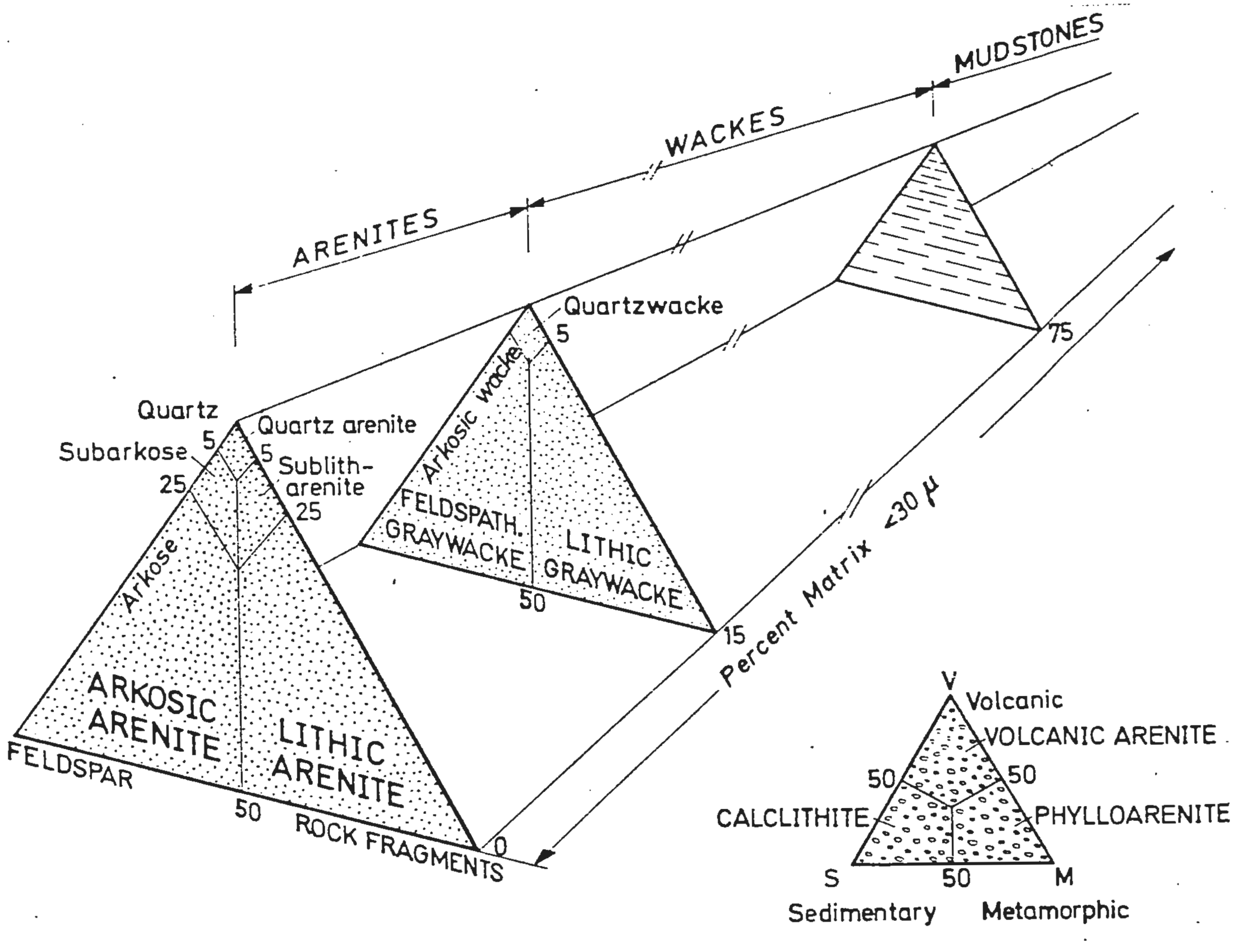

Figure 4.13 Classification of sandstones (Revised by Pettijohn and others, 1973, from Dott, 1964).

study area (Unit 3) is much more schistose and deformed as shown in Figure 4.14a. The few definitely detrital grains are coarse-grained sand and granules. Plagioclase grains exhibit less deformation than polycrystalline quartz grains as shown in Figure 4.14b. The biotite is a brown biotite, locally green, up to 0.5 mm in length. Minor chlorite is present. Table 4.4 shows modal analyses results.

Stained heels show both elongated quartz and plagioclase separated by biotite and sericite laminae.The plagioclase averages 23% according to stained thin section heels. Alkali feldspar averages 4-5%.

The sandstone in the area east of Mine Centre along Highway 11 contain local chert pebble conglomerate interbeds.

Heavy Mineral Analyses

Heavy mineral separations yielded a suite containing abundant biotite that is probably iron-rich because of its green color, actinolite, apatite, and minor sphene; all are metamorphic products. Subangular pink zircons, along with rare tourmaline, are the only clearly detrital components. The tourmaline identified is subrounded with an abraded surface suggesting a detrital source. Magnetite and ilmenite are abundant in the magnetic fraction.

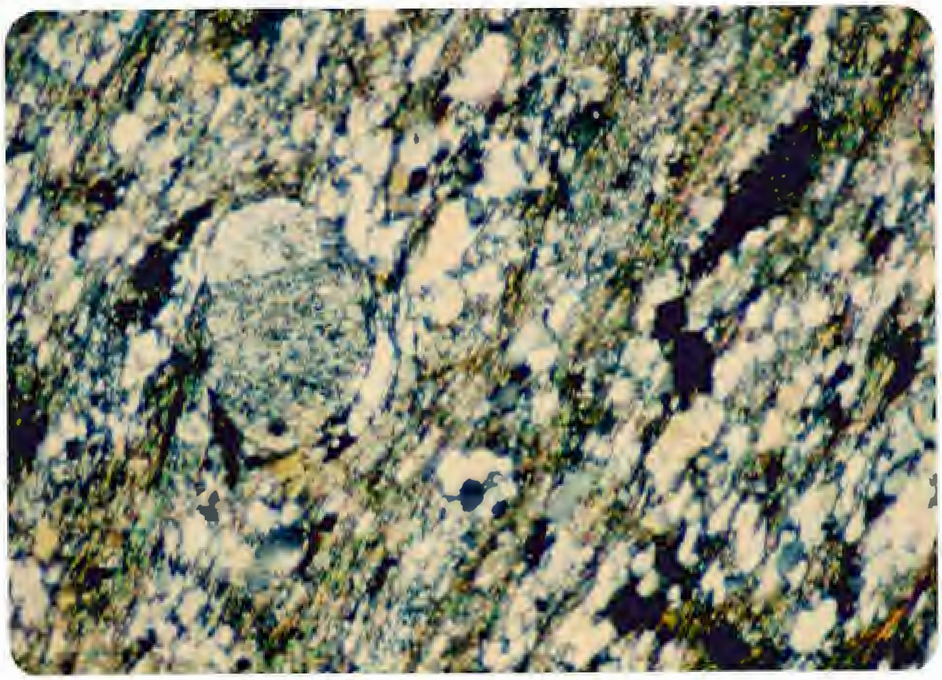

Figure 4.14a Photomicrograph of Seine Group sandstone Unit 3 (schistose), of the eastern part of the study area. Note the less deformed plagioclase-bearing rock fragment (most likely a granitic rock fragment or porphyritic volcanic) surrounded by finer-grained deformed quartz and biotite (field of view=2.4 mm wide, crossed nicols).

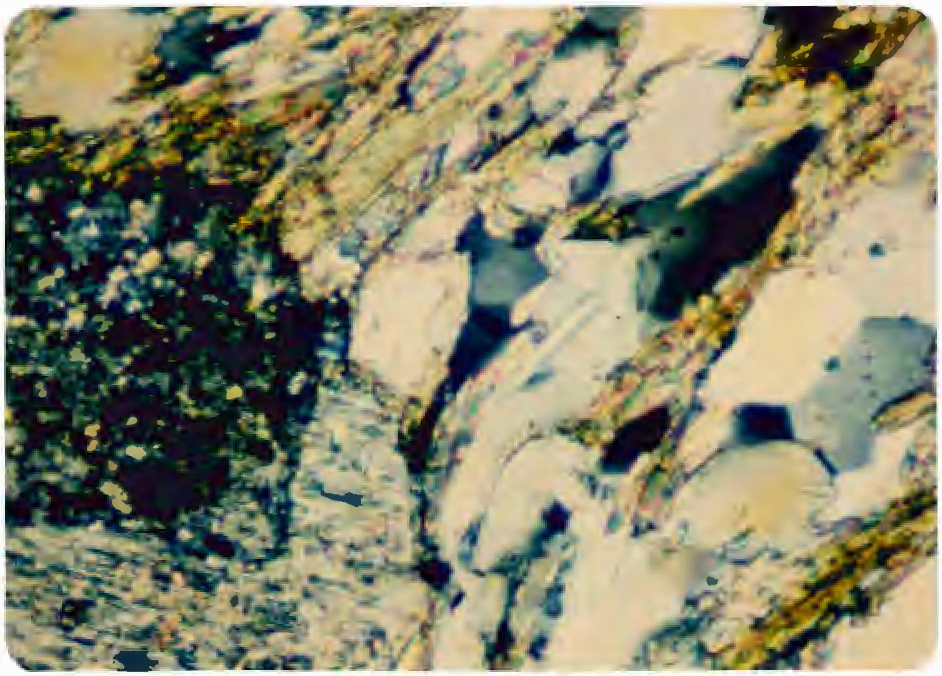

Figure 4.14b Photomicrograph of deformed Seine Group sandstone shown in Figure 4.14a, utilizing greater magnification to exhibit the deformation varieties exhibited in different grains (field of view=0.5 mm wide, crossed nicols).

Sample	MC31	MC37	MC40	MC46	MC48
Quartz	46	35	50	44	58
Feldspar					
Plagioclase	44	25	23	34	21
Alkali Feldspar	1	0	9	2	6
Total Feldspar	48	25	32	36	27
Micas					
Biotite	-	15	-	5	-
Muscovite	-	20	-	10	-
Chlorite	-	5	-	5	-
Total Micas	8	40	18	20	15

Table 4.4 Thin section modal analyses of Seine Group sandstone, Unit 3 (schistose), of the eastern part of the study area.

Chapter 5

STRUCTURE AND METAMORPHISM

Structure

In the Rainy Lake area, metamorphism and cataclasis have obliterated many original sedimentary structures. Documentation of polyphase deformation in the area makes clear the reason for conflicting interpretations regarding stratigraphy by many workers. Many structural indicators including beds, cross-beds, and graded beds indicate a southward-topping direction for the Seine Group, as shown in Figure 5.1. Bedding consistently strikes east-northeast and dips nearly vertical; poles to bedding in the study area are plotted in Figure 5.2. Figure 5.3 is a diagrammatic cross-section of the western part of the study area. Penetrative foliation is well developed throughout the belt of supracrustals and is often nearly parallel to bedding or intersects it at less than 15 degrees. Foliation shows a consistent orientation throughout the area; it strikes east-northeast and dips nearly vertical and approximately parallels the axial trace of major folds. Poles to schistosity are plotted in Figure 5.4. Mineral lineations are found in the foliation plane and vary in plunge from 30 to 70 degrees, mostly to the east-northeast as shown in Figure 5.5.

Figure 5.1 Graded beds of Seine Group feldspathic sandstone fining upward (to the south) at RL79 in the western part of the study area.

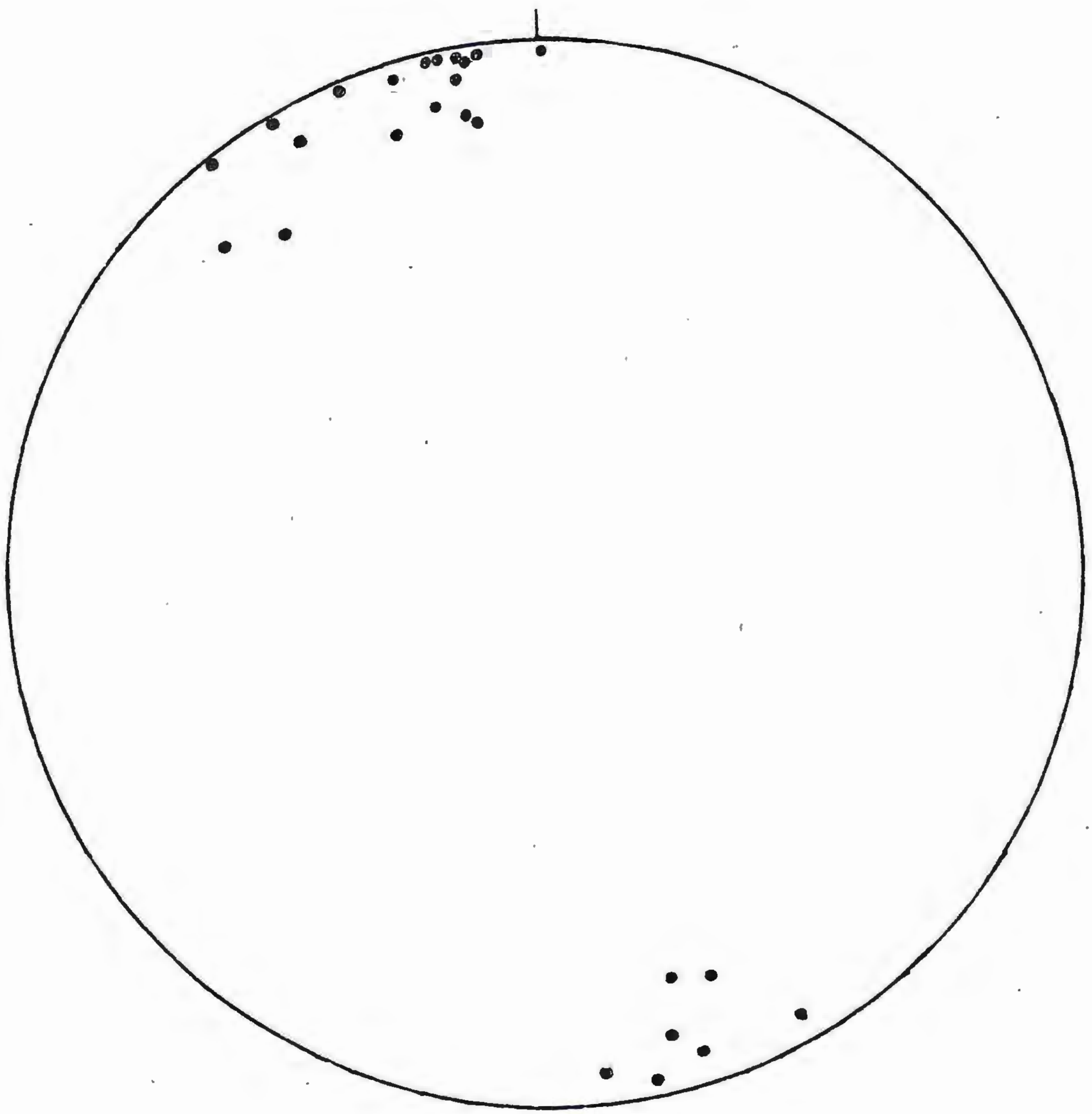

Figure 5.2 Plot of poles to S_0 bedding in the area of study.

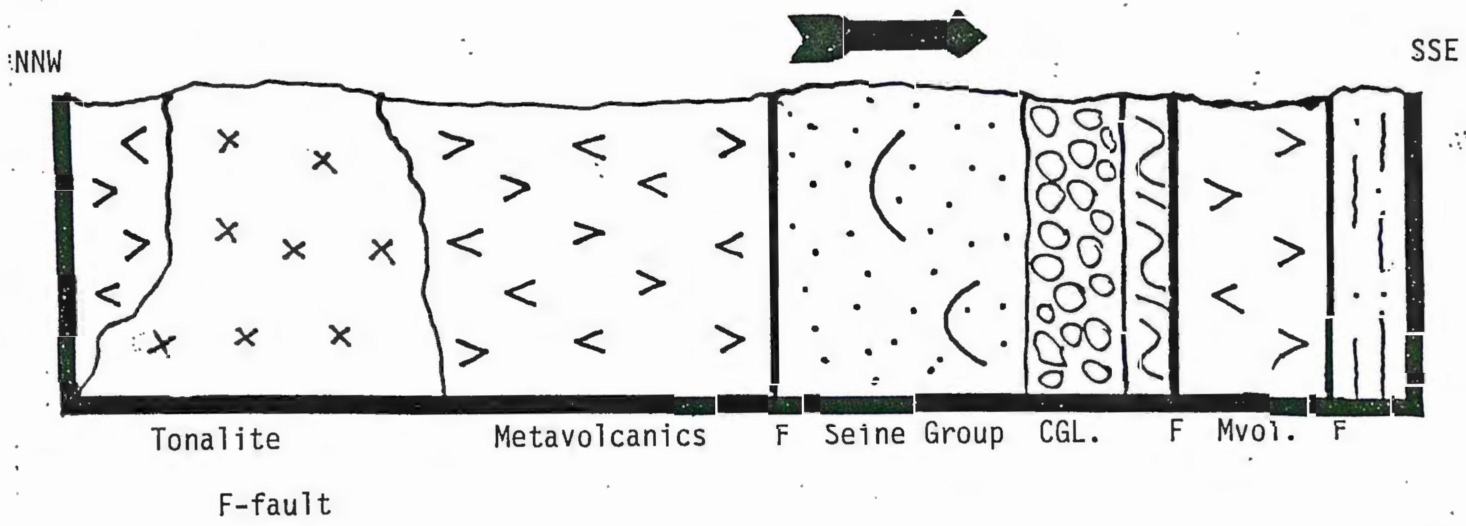

Figure 5.3 Diagrammatic NNW-SSE cross-section of the western part of the study area (arrow shows up direction, F is fault; After Ojakangas, 1972).

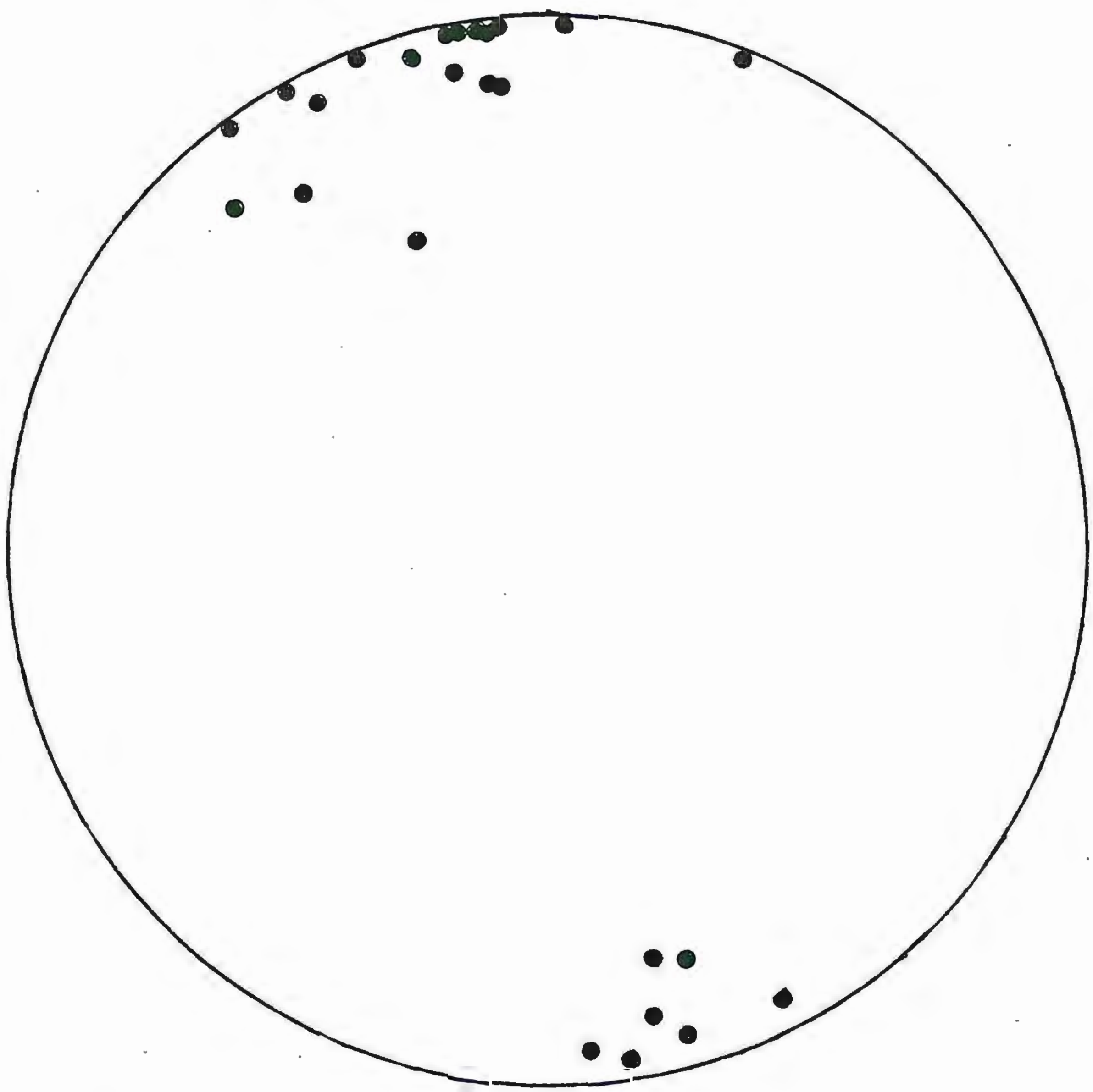

Figure 5.4 Plot of poles to S_1 schistosity of the Seine Group in the area of study.

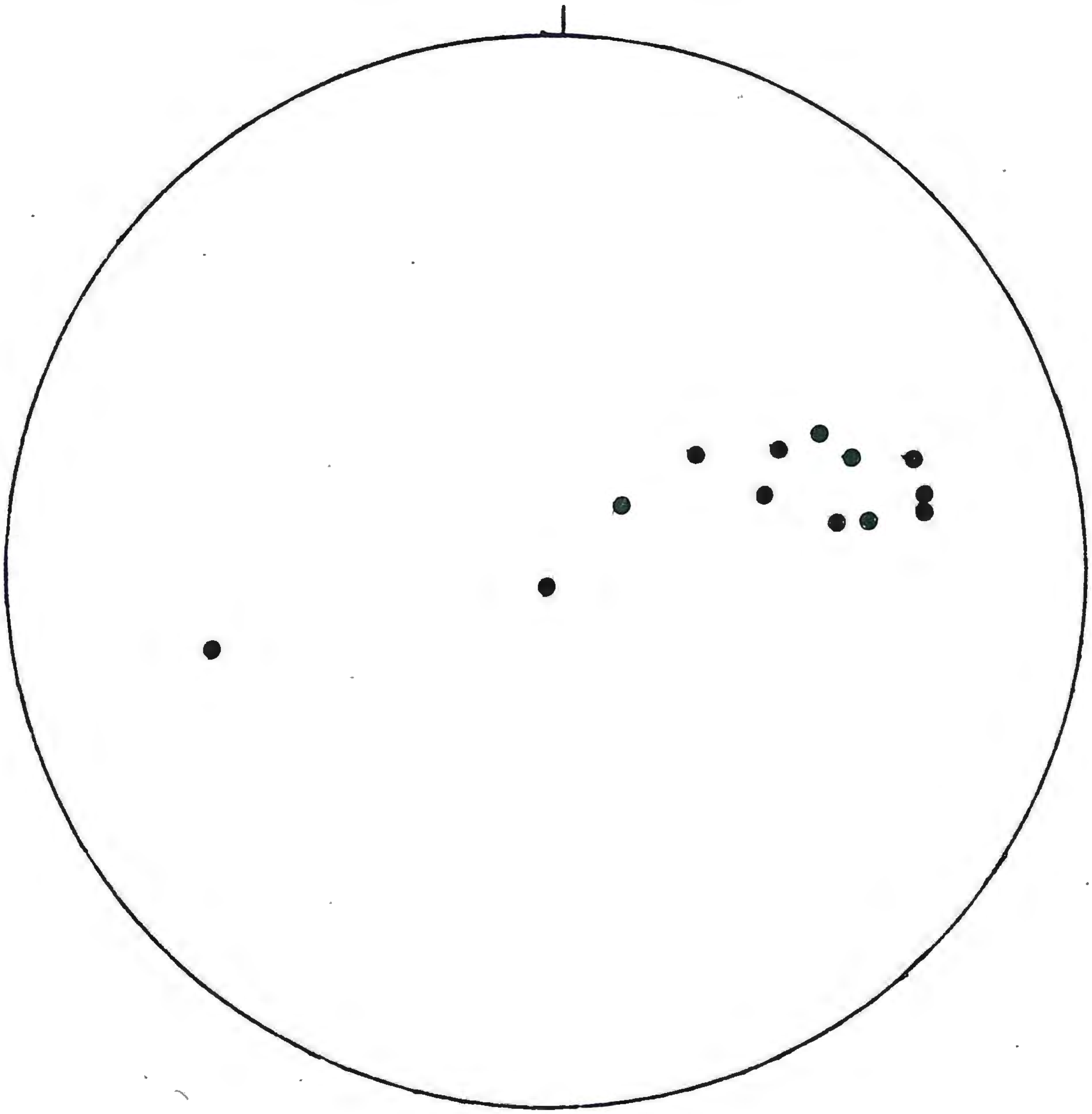

Figure 5.5 Trend and plunge of lineations measured on outcrops of the Seine Group.

The contact of the meta-sandstone with the metavolcanic rocks in the western part of the study area along the north side of Grindstone and Dryweed Islands is manifested as a linear trough that shows well on the topographic map as a lineament. This is interpreted as a fault contact. The contact of the metavolcanics above (south of) the feldspathic sandstone exhibited on Big American Island and on the south side of Dryweed Island is also interpreted as a fault contact due to the intensely sheared nature of the overlying metavolcanic rocks.

Folds

Folds, both small-scale and large-scale, are present in the area. Refolding appears to have occurred in the western part of the study area and Hsu (1971) reported a relationship of folding to intrusions in the eastern part of the study area. A geometric analysis of fabric at Rice Bay by Poulsen (1979) revealed the presence of a major antiform with moderate plunges. Part of the sequence is downward-facing, implying that the sequence was overturned by an episode of F_1 folding which predated the F_2 event. At Bears Passage structurally overturned strata favor the stratigraphic placement of the Coutchiching upon the Keewatin. Poulsen and others (1980) noted that regional axial surfaces of F_2 folds strike nearly east-west and dip steeply, and that a penetrative cleavage is axial planar to F_2 folds. They also noted that bedding-cleavage intersection lineations are coaxial with F_2 fold axes.

Day (1984) recognized three phases of deformation in the area. The first consists of large-scale folds which are exhibited best in the meta-graywackes. These F_1 folds are tight and noncylindrical with axial planes striking N65E. An early F_1 regional schistosity is developed axial planar to the folds and is shown in Day's plot in Figure 5.6. Day summarized D_1 as a period of strong flattening. The second deformation D_2 produced a strong S_2 cleavage. This schistosity is axial planar to small F_2 folds. Day's plots of F_1 and F_2 fold axes are shown in Figure 5.7. The third deformation produced high-angle faults and shear zones, the major ones being the Rainy Lake-Seine River fault and the Quetico fault.

Hawley (1930) interpreted horizontal motion on the Rainy Lake-Seine River fault as dextral. The higher metamorphic grade present in the rocks on the south side of the fault was explained as a result of the southern block also moving upward, exposing deeper parts of the pile (Ojakangas, 1972).

Pebbles in the conglomerate in the eastern part of the study area show distinct deformation (Figure 3.2). The deformation path of the deformed clasts has a slope of 2.74 so the strain ellipsoid is of the flattening type which

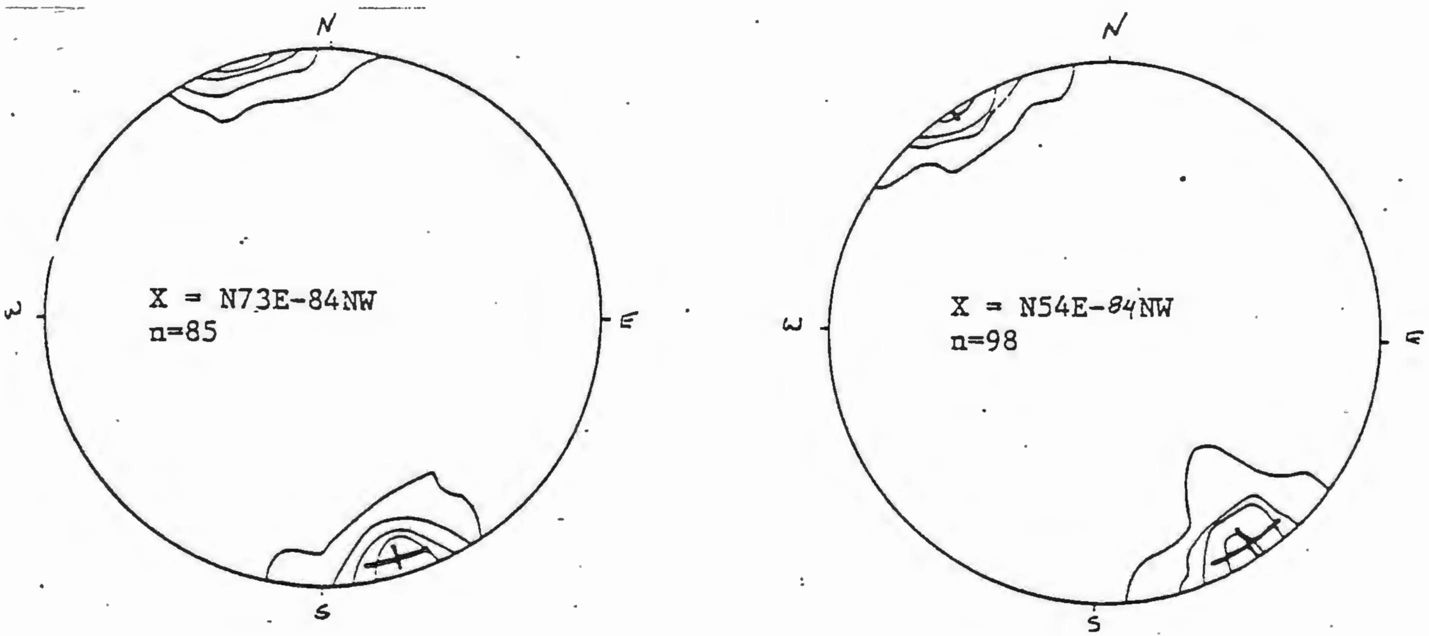

Figure 5.6 Day's (1984) poles to S_1 schistosity and S_2 cleavage for the Rainy Lake area.

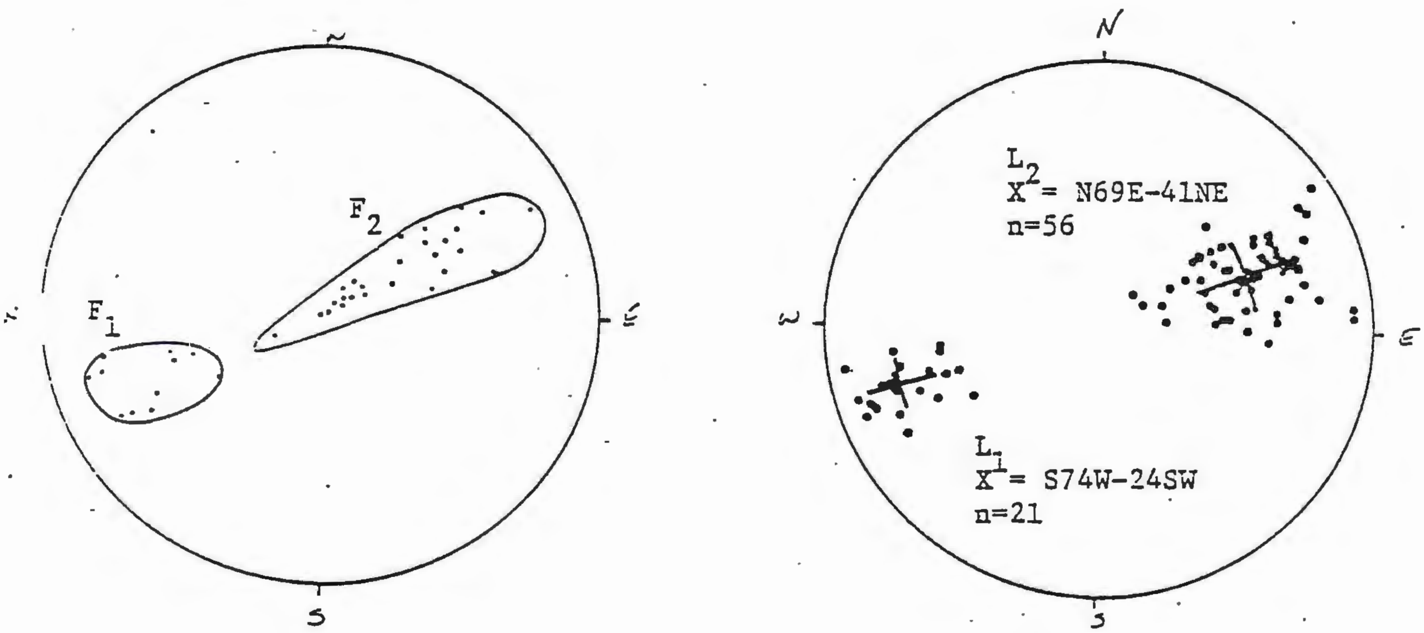

Figure 5.7 Day's (1984) trend and plunge of fold axes and mineral lineations for the Rainy Lake area.

is consistent with the poor regional development of mineral lineations in strongly foliated rocks (Hsu 1971). Hsu also found the average shortening of volcanic pebbles in the Shoal Lake area equal to 60%, 37% in quartzose pebbles, and only 7% in granitic cobbles. Most of the volcanic clasts are cobble-size while the quartz and arenite clasts are generally pebbles. Hsu (1971) presented an explanation for ductile deformation of granitic cobbles under low-grade P-T conditions at a very low strain rate.

Metamorphism

Metamorphic grade in the feldspathic sandstone and conglomerate is commonly greenschist facies. Just north of the Quetico Fault the metamorphic grade is amphibolite whereas to the south it is greenschist facies. In general, the metamorphic grade increases southward, but in the wedge bounded by the faults (Plate 2), the pattern is reversed (Poulsen, 1984). Figure 5.8 is Blackburn's (1982) map of metamorphic zones of the study area in Canada.

The metamorphism of the feldspathic sandstone is characterized by a mineral assemblage of sericite-muscovite and quartz with minor biotite. The original clastic textures of the sandstone and the matrix of the conglomerate are generally well-preserved, except where sheared.

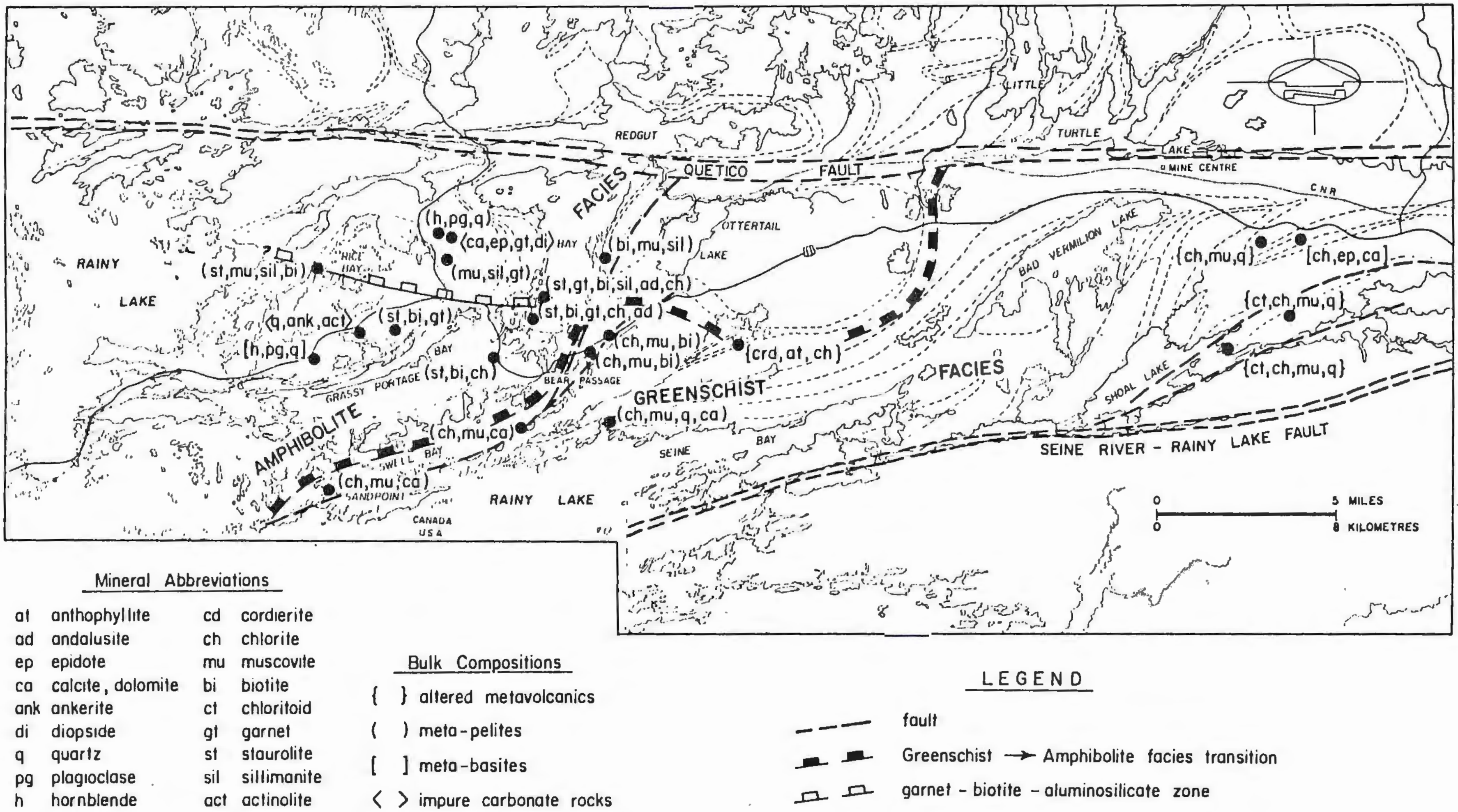

Figure 5.8 Map of metamorphic zones for the area between the Quetico and the Rainy Lake-Seine River Faults (From Blackburn and others, 1985).

Chapter 6

SEDIMENTATION

Introduction

Fluvial deposition of the Seine Group was proposed as early as 1913 when Lawson suggested that the Seine was an Archean river deposit. Pettijohn (1943) did the first work on Archean sediments of the Superior province, and concluded that they resembled glacial varves. Goodwin (1968) and McGlynn (1970) considered Archean sediments to be typically flysch-like and subplatformal. Ojakangas (1985) reported that sedimentation in the Archean was dominated by the resedimented association of greywacke, mudstone and conglomerate, generally on submarine fans. He recognized the fluvial and alluvial fan facies as volumetrically less important.

Many modern gravelly environments have been investigated, but many ancient depositional systems may have no modern analogues because of differences in vegetation. Facies analysis requires distinguishing specific sedimentary sequences which may be typical of a particular process. Facies are used in the present study in both an interpretive and descriptive sense; they refer to certain observable properties of sedimentary rocks which can be interpreted in terms of a depositional process. An individual lithofacies is defined (according to Miall, 1984) as a rock unit of distinctive features including composition, grain size, bedding characteristics, and sedimentary structures. Each lithofacies represents an event and may be grouped into lithofacies associations or assemblages, characteristic of particular depositional environments. Table 6.1 shows the lithofacies associations from Miall (1978) and Rust (1978), used in this study.

Turner and Walker (1973) stated "the dice are loaded against the sedimentologist because of structural deformation, lack of availability of paleocurrent data, and general absence of long, unbroken, and continuously exposed stratigraphic sections." They identified the problems of interpretation in Archean rocks as beginning where sands thicken, become more massive, and lack shale layers.

Nemec and Steel (1983) have reported that gravel deposits from ephemeral flooding, especially alluvial fan stream deposits, tend to be immature. Characteristics include vague to distinct stratification, widespread imbrication and a lack of well-defined beds. Alluvial fans may be recognized by coarse facies banked against the basin margin.

Ojakangas (1985) noted that the interpreted lateral gradations of alluvial fan/fluvial to turbidite deposition of the Archean sediments, exhibit a notable lack of shelf

Major facies —	Gm:	Clast-supported. commonly imbricate gravel with poorly defined sub-horizontal bedding.
	Gms:	Muddy matrix-supported gravel without imbrication or internal stratification
	Gt:	Trough cross-bedded clast-supported gravel
	Gp:	Planar cross-bedded gravel. transitional from clast-supported gravel through sand matrix-supported gravel to sand (Sp)
Minor facies —	Sh:	Horizontally stratified sand
	St:	Trough cross-stratified sand
	Sp:	Planar cross-stratified sand
	Fm:	Massive fine sandy mud or mud
	Fl:	Laminated or cross-laminated very fine sand, silt or mud
	P:	Pedogenic concretionary carbonate

Table 6.1 Facies typical of fans and braidplain deposits (From Rust, 1978).

deposits.

Miall (1978) defined six principal lithofacies types for gravel-sand dominated braided river deposits as shown in Table 6.2. Figure 6.1 shows the resultant vertical profiles for the six types. The Scott type is present on alluvial fans beyond the limit of debris flows. Miall contended that the Scott type sedimentation is dominated by superimposed longitudinal bar deposits that represent flood processes. Minor sand facies are deposited during low water episodes as in abandoned channels. The South Saskatchewan type is made up of channels commonly flooded by lag gravels; bedforms in deeper channels tend to be sinuous-crested dunes consisting of lithofacies St, meaning sandstone with trough cross-beds.

Sedimentation of the Seine Group

The Seine Group conglomerates appear to be most similar to a Scott type depositional setting while the sandstone (Unit 3; see Figure 3.1) most likely is a combination of the Scott and the South Saskatchewan types.

The bulk of the accumulation of the Seine Group is feldspathic sandstone and polymict clast-supported conglomerate. The feldspathic sandstones are characterized by moderate-poor sorting, subrounded grains, immature compositions and a fairly high percentage of

Name	Environmental setting	Main facies	Minor facies
Trollheim type (G_I)	proximal rivers (predominantly alluvial fans) subject to debris flows	*Gms, Gm*	*St, Sp, Fl, Fm*
Scott type (G_{II})	proximal rivers (including alluvial fans) with stream flows	*Gm*	*Gp, Gt, Sp, St, Sr, Fl, Fm*
Donjek type (G_{III})	distal gravelly rivers (cyclic deposits)	*Gm, Gt, St*	*Gp, Sh, Sr, Sp, Fl, Fm*
South Saskatchewan type (S_{II})	sandy braided rivers (cyclic deposits)	*St*	*Sp, Se, Sr, Sh, Ss, Sl, Gm, Fl, Fm*
Platte type (S_{II})	sandy braided rivers (virtually non cyclic)	*St, Sp*	*Sh, Sr, Ss, Gm, Fl, Fm*
Bijou Creek type (S_I)	Ephemeral or perennial rivers subject to flash floods	*Sh, Sl*	*Sp, Sr*

Table 6.2 The six principal lithofacies assemblage models for gravel and sand dominated braided river deposits (From Miall, 1978).

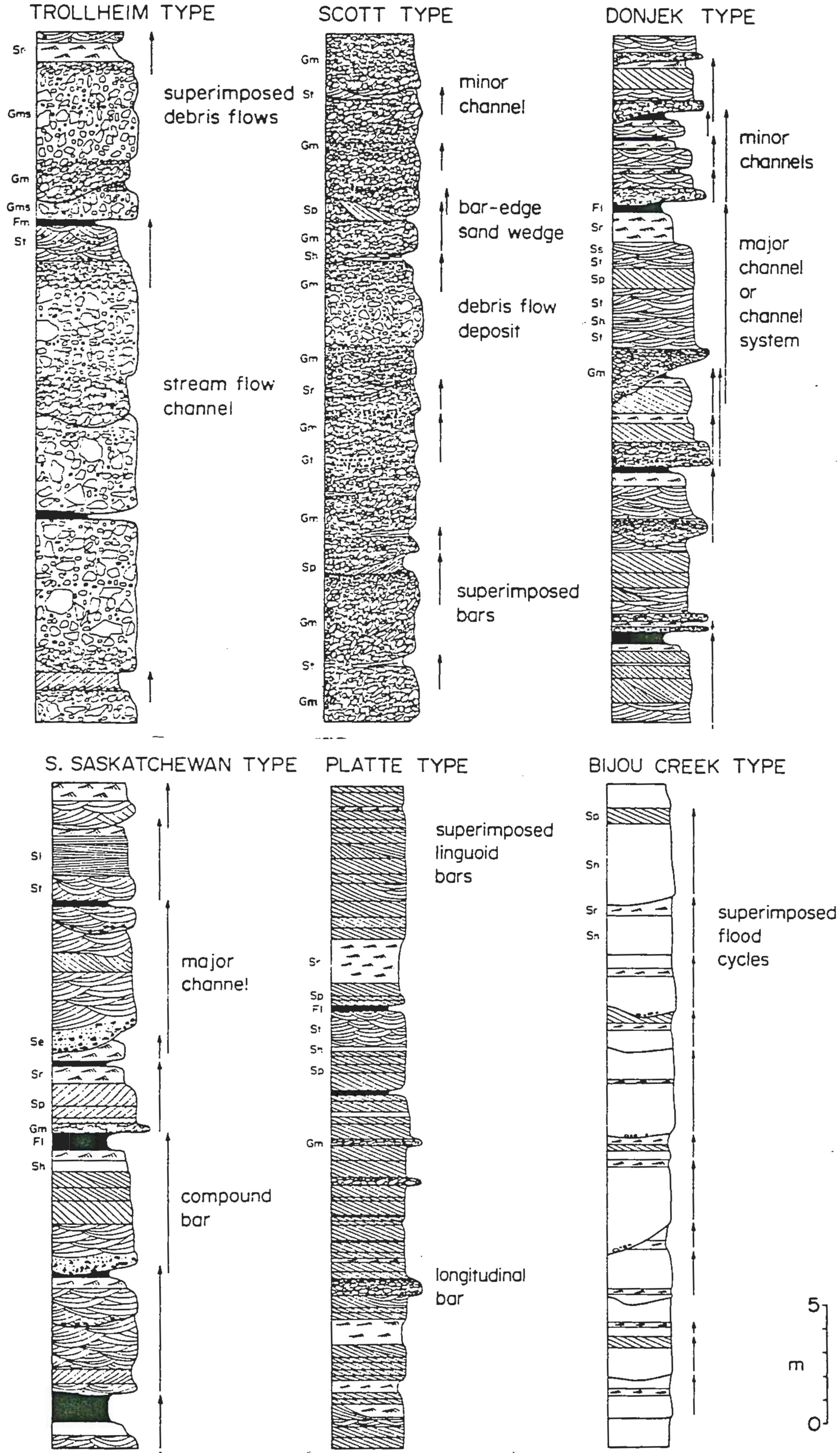

Figure 6.1 Generalized vertical profiles for the six braided river depostional models of Miall (From Miall, 1978).

matrix material. Using modern sedimentological criteria it is proposed that the Seine Group has been deposited by both alluvial fan and fluvial depositional environment. A middle to distal alluvial environment such as shown in Figure 6.2 may represent the environment of deposition of the sandstones and minor siltstones.

The Seine Group conglomerates and sandstones contain the following five lithofacies: orthoconglomerate, volcanic sandstone, and feldspathic sandstone, plus minor associated mudstone and paraconglomerate. Figure 6.3, a measured section of the orthoconglomerate in the western part of the study area (Neil Point) has been divided into the sedimentary facies developed by Rust (1978). Field descriptions of each of the lithofacies follows.

The orthoconglomerate facies occurs at the bottom of the sequence in the eastern area and higher up in the western part of the study area at Neil Point. It includes the subfacies of basal conglomerate and massive conglomerate with pebbly volcanic sandstone interbeds. The thickness of the unit varies as it forms a mega-lense in the stratigraphic pile. The unit is generally poorly sorted, consisting of subrounded and minor subangular clasts. The alignment of the clasts nearly parallel to bedding is a result of sedimentation at high velocities. Individual beds are massive and up to 20 meters thick, most

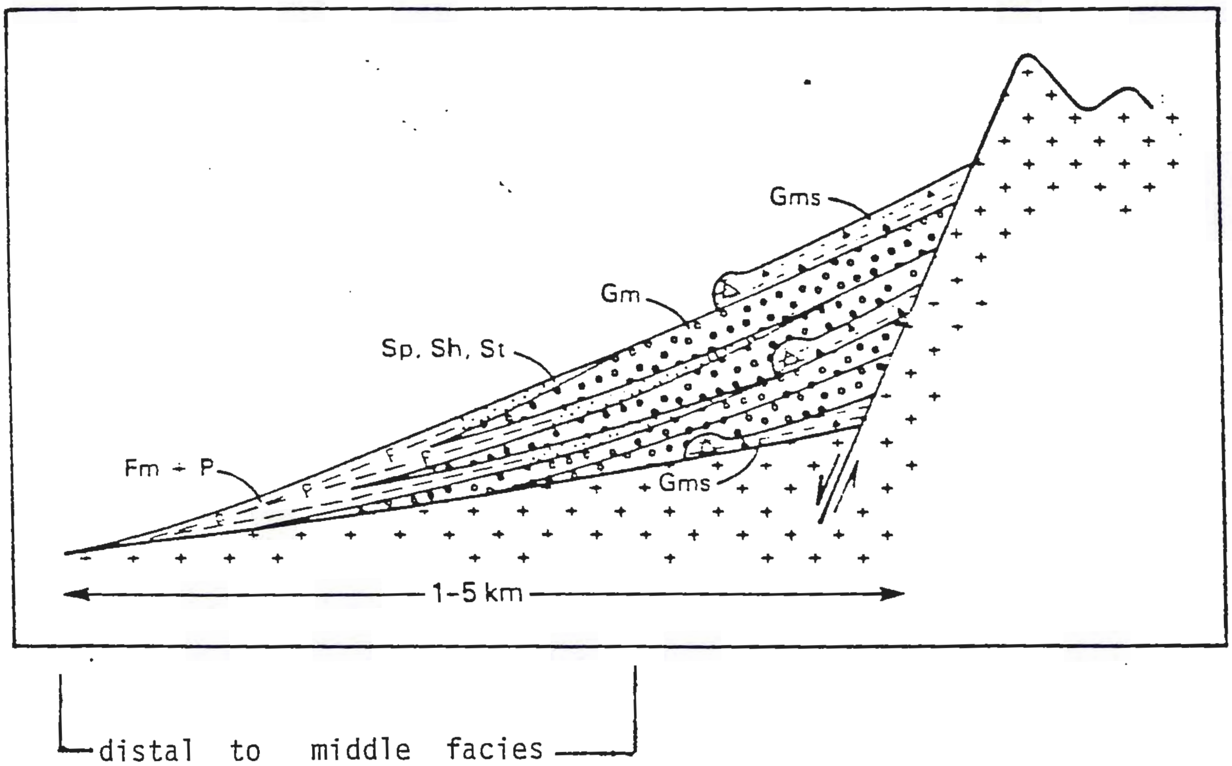

Figure 6.2 Diagrammatic cross-section showing the middle to distal facies of an alluvial fan as proposed deposition of the Seine Group (After Rust, 1978).

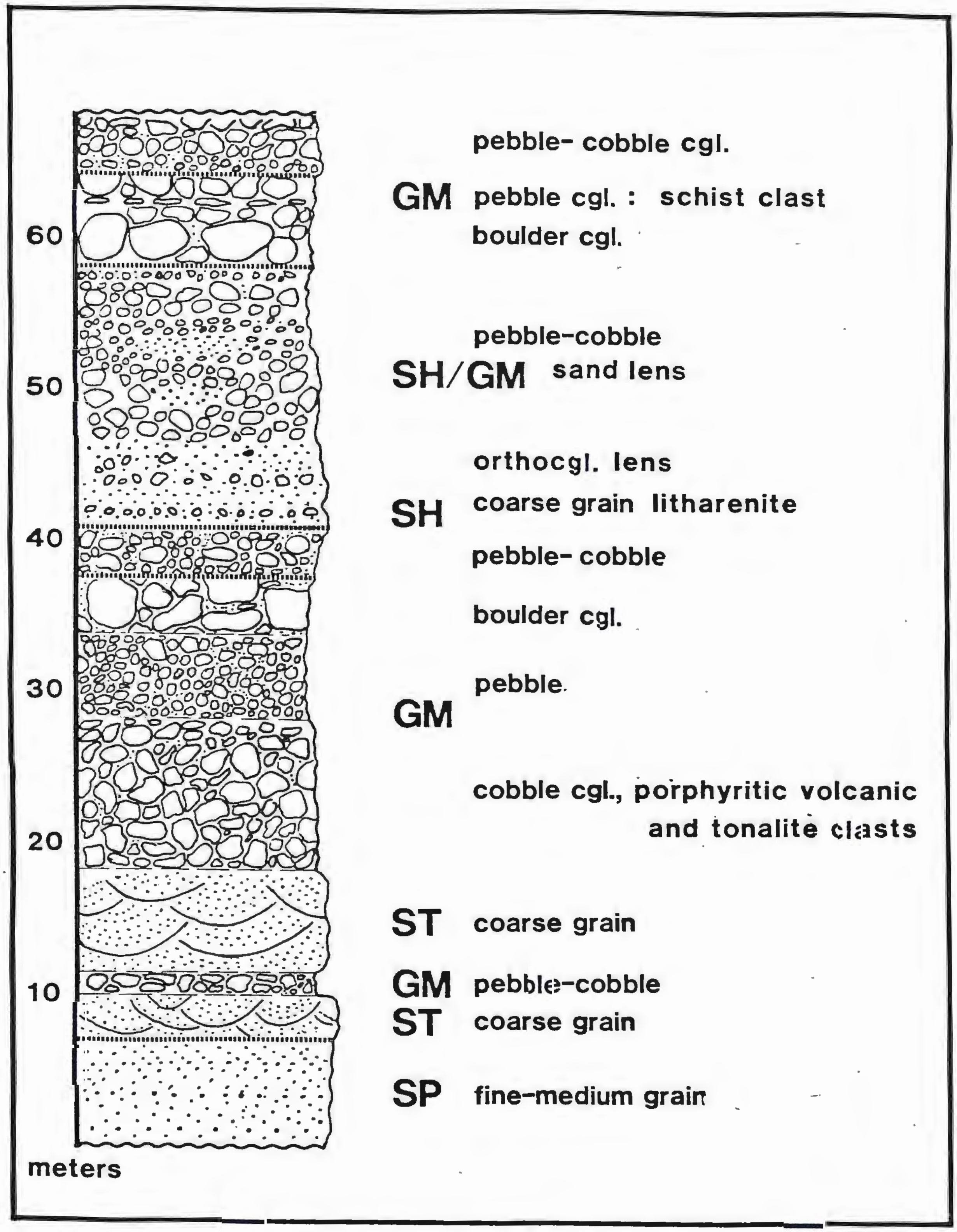

Figure 6.3 Measured Section of the Seine Group conglomerate (Unit 5) on Neil Point with lithofacies interpretations (After Miall, 1978).

commonly between one and 10 meters. The conglomerates do not appear to be cross-stratified, graded, or imbricated. It is notable that there is no apparent regular decrease or increase in bed thickness upward.

The volcanic sandstone facies is made up of volcanic sandstone interbeds within the conglomerate that vary from 10 cm to a maximum of 2 meters; one meter thick interbeds are the average. These beds are not cross-stratified and exhibit no sedimentary structures except for parallel bedding. Within the volcanic sandstone there are some beds 20 cm to 1 meter thick which contain scattered volcanic pebbles that are normally not touching each other, as shown in Figure 6.4. Many interbeds and pebbly layers continue across the width of the outcrop and others die out within a few meters.

The feldspathic sandstone facies characteristically is either massive or has abundant cross-stratification. Bedding is usually noted by changes in grain size. Cross-stratification is best exposed in the western part of the study area and is distributed throughout the range of the arkosic facies. Turner and Walker (1973) noted the importance of the accurate use of the word "cross-bedding." Cross-stratification is mostly of low-to-high angle trough type. Individual sets average 7-50 cm thick and are usually partly obscured, making it difficult to determine

Figure 6.4 Pebble-bearing volcanic sandstone interbed with the conglomerate on Neil Point at RL60.

width and length. Lower contacts of foresets are assymptotic and usually gently curved (Figure 6.5). Locally, symmetrical troughs are observed. Cross-strata are marked by changes in grain size between laminae, and locally by darker laminae with greater contents of biotite and chorite. At some locations cross-stratification is of the planar type. Parallel laminations also occur in beds. Mudchip conglomeratic beds are exhibited locally as shown in Figure 6.6. Textural changes between adjacent laminae indicate a sedimentary origin rather than a tectonic origin for the laminations. Graded bedding in the arkosic arenite occurs at a few localities such as along the County Road 11 (Figure 5.1); these beds range in thickness from 2-10 cm, are sharp based, and fine upward from coarse sand to fine sand.

The mudstone lithofacies has been metamorphosed to a fine-grained quartz-rich schist with abundant biotite and muscovite. Laminations are the only sedimentary structures exhibited, and interbeds of this lithofacies are more common in the eastern part of the study area than in the western part.

The paraconglomerate facies is only present at one locality in the western part of the area, and consists of a matrix-supported conglomerate of volcanic and plutonic clasts in a muddy matrix.

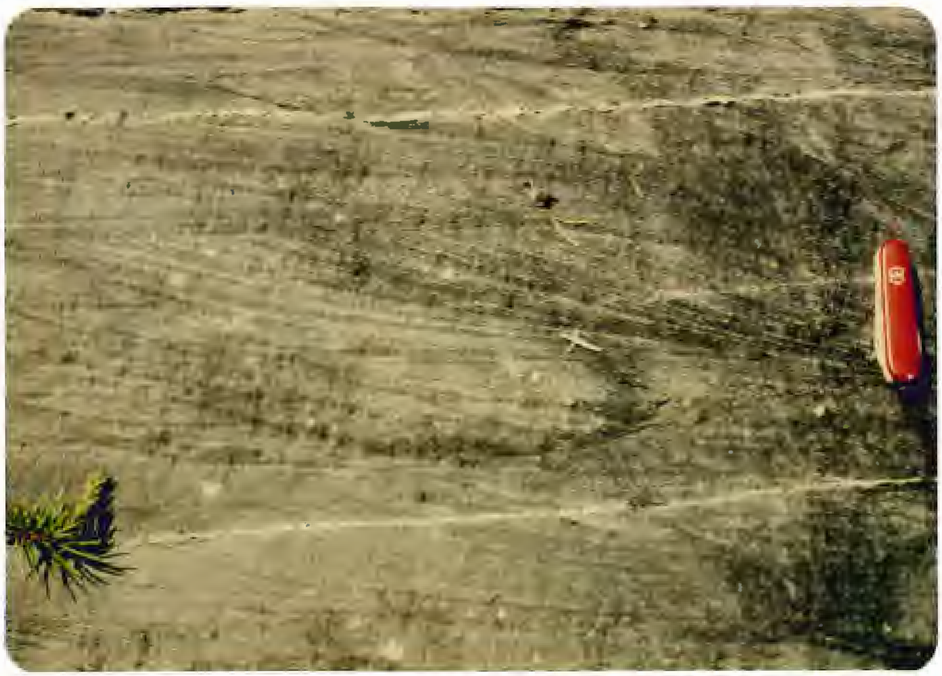

Figure 6.5 Trough cross-bedding in the Seine Group sandstone at location MC134.

Figure 6.6 Mudchip conglomerate bed within the Seine Group feldspathic sandstone on Dryweed Island at location RL167 in the western part of the study area.

The conglomerate (units 1, 2, and 5; Figure 3.1) is massive and crudely bedded. Units 2 and 5 exhibit interbedded sandstones and locally, exhibit well-developed parallel planar stratification in the orthoconglomerate. Erosional surfaces, where recognizable, are curved, a characteristic of the combined effect of both entrenching and avulsive behavior, and the shifting and abandonment of individual channels (Nemec and Steel, 1983). These conglomerates are interpreted as having been deposited by an alluvial system on a basin margin, near uplifted highlands. The slope at the basin margin must have been relatively steep since tonalitic clasts up to 80 cm in diameter have been transported and some beds contain angular clasts. There is no evidence of slumping or turbidity currents.

In the Shoal Lake area the granite-bearing conglomerates grade upward into pebbly sandstone and sandstone; these lithic sandstone interbeds may be the down-current equivalent of the conglomerate. Hsu (1971) reported that these interbeds suggest that the conglomerate in the Shoal Lake area is a product of resedimentation. Hsu stated that the sand interbeds were deposited from suspended materials accompanying the mass movement of pebbles. The present author disagrees with his model.

Since the conglomerate and sandstone are in a vertical attitude, there is no evidence to indicate whether or not they rapidly thin in the down-dip direction, as is typical of basin-margin accumulations. Conglomerates originating in alluvial environments have braided stream, distributary, sheet flood-stream, and mass flow sequences. Basin alluvial-fan deposits normally rest nonconformably on bedrock and contain blocks and boulders of that bedrock within the conglomerate. This type of basal contact, as exhibited near the Shoal Lake Road and Bad Vermillion Lake, is unknown in deep basin conglomerates and is uncommon in fluvial conglomerates (Turner and Walker, 1973). Conglomerate beds range in thickness from single cobble layers to massive beds as thick as 20 meters. These thicker beds appear to be deposited in channels but the dimensions of these channels are difficult to measure due to the lack of good outcrop. Most beds consist of subrounded cobbles. In the western part of the area, the basal conglomerate sequence is "missing" due to non-deposition or possibly faulting. The upper conglomerate, Unit 5 with interbedded volcanic sandstone, is made up of subrounded to well-rounded cobbles and boulders interpreted as a middle to distal alluvial deposit.

In general, the feldspathic sandstone is marked by cross-stratification, absence of ripple marks, and an association with volcanic rocks. It is present in accumulations up to 950 meters thick; as on Neil Point. All features may be included in an island-arc environment where deposited. This type of environment has been proposed for other volcanic sedimentary belts of the Canadian Shield. The feldspathic sandstone and orthoconglomerate share a common environment of deposition. Basic characteristics of this sandstone facies include the thick and massive beds, the basal beds resting nonconformably on the intrusives and volcanics (Figure 6.7), and evidence of strong current activity including 10 cm thick sets of cross-beds. The conglomerates are not cross-stratified nor graded. The conglomerate and feldspathic sandstone sequences can develop in modern environments including deep basinal, coastal (beach conglomerate), fluvial (braided stream conglomerate), subaerial (alluvial and piedmont fanglomerate) and glacial. Turner and Walker (1973) suggested that the presence of associated arkoses rules out any beach interpretation and that the Archean arkoses are unlike any known shallow marine or floodplain deposits behind the beach. This author agrees with their interpretation. Greenstone pebbles would not survive the high energy of the beach environment (Turner and Walker, 1973). Tillites are characteristically paraconglomerates with a clayey matrix.

Figure 6.7 Seine Group feldspathic sandstone lying unconformably(?) upon Archean metavolcanics in the eastern part of the study area at location MC24.

Deep basin, shoreline, braided fluvial and glacial environments are rejected because of the lack of many diagnostic characteristics. On modern alluvial fans, sediment is either waterlain or deposited as fan debris flows (Hooke, 1967). Waterlain beds may have been deposited from sheetfloods or storm surges, sieve deposits or back-filled and incised channels. Turner and Walker (1973), studying the Ament Bay Formation at Sioux Lookout, Ontario, suggested that sufficient volumes of fines were not available in the source area to initiate mudflows.

The lack of mud layers in the deposits fits the alluvial fan-braided stream model, whereas mud would be abundant on the floodplain of meandering river systems. Local siltstone and mudstone beds that are present may represent minor interbar or bar-top deposits. Wood (1980) interpreted the Seine Group as having been deposited in an environment composed of alluvial fans merging into braided fluvial plains.

The alluvial fan-braided stream facies includes the clast-supported conglomerates and sandstones of this study with medium-to large-scale cross-bedding. Sedimentation most likely proceeded throughout Seine time with little interruption, as evidenced by the lack of recognizable unconformities between members. It appears that the Seine conglomerate and feldspathic sandstone are waterlain, probably sheetflood and storm surge deposits. Turner and Walker (1973) suggested a shallow depth, 30-60 cm., as the flow spreads out on a fan from the end of a channel. The appearance of parallel laminae and cross-bedding within the feldspathic sandstone sequence implies lower energy fluid flow in shallow channels. The massive sandstones imply sheetfloods that were sediment-laden, and that sediment was very rapidly deposited. Pebbly layers within the arkoses may represent lags of coarse material laid down as the sheetfloods begin to wane. Massive conglomerates may be storm surge deposits.

Extensive areas of Quetico-type turbiditic sedimentary rocks are not found north of the Rainy Lake-Seine River Fault; this marks a change in the environment of deposition south of the fault (Ojakangas, 1972).

Paleocurrent Analysis

Regional paleocurrent patterns are produced by plotting data as rose current diagrams. Despite the presence of cross-bedding, the nature of outcrop is such that conventional paleocurrent work is difficult. Indicated current direction and structure type (thickness of cross-beds, depth of troughs, length of cross-beds, and clast size) were noted for each measurement.

In regions of folded strata, directional sedimentary structures no longer retain original orientation. If the fold axis is not horizontal, there may have been rotation about two axes. Correction for tilt in this case involves first a correction for plunge, and second for the residual tilt (Ramsay, 1961; and Potter and Pettijohn, 1977). This method assumes that the deformation was uncomplicated tilt or simple flexural folding with plunge. In more severely deformed and faulted areas, such as this study area, shear folding and compression also distort the sedimentary structures. Correction for such distortions is subject to uncertainties.

Rotations for one simple tilt were carried out by correcting the field data on a stereonet. Sets of readings were grouped to produce the current rose diagrams shown in Figures 6.8a and b, 6.9a and b, and 6.10a and b for the eastern and western parts of the study area. These diagrams represent the data which have been corrected for simple tilt. The data are unimodal and suggest that paleocurrents were generally flowing to the southwest. Note that the trough axis measurements are commonly nondirectional because some outcrops were too two-dimensional and it was impossible to measure a sense of flow direction. These trough axes were plotted so as to show both directions, and they do not suggest bimodal currents.

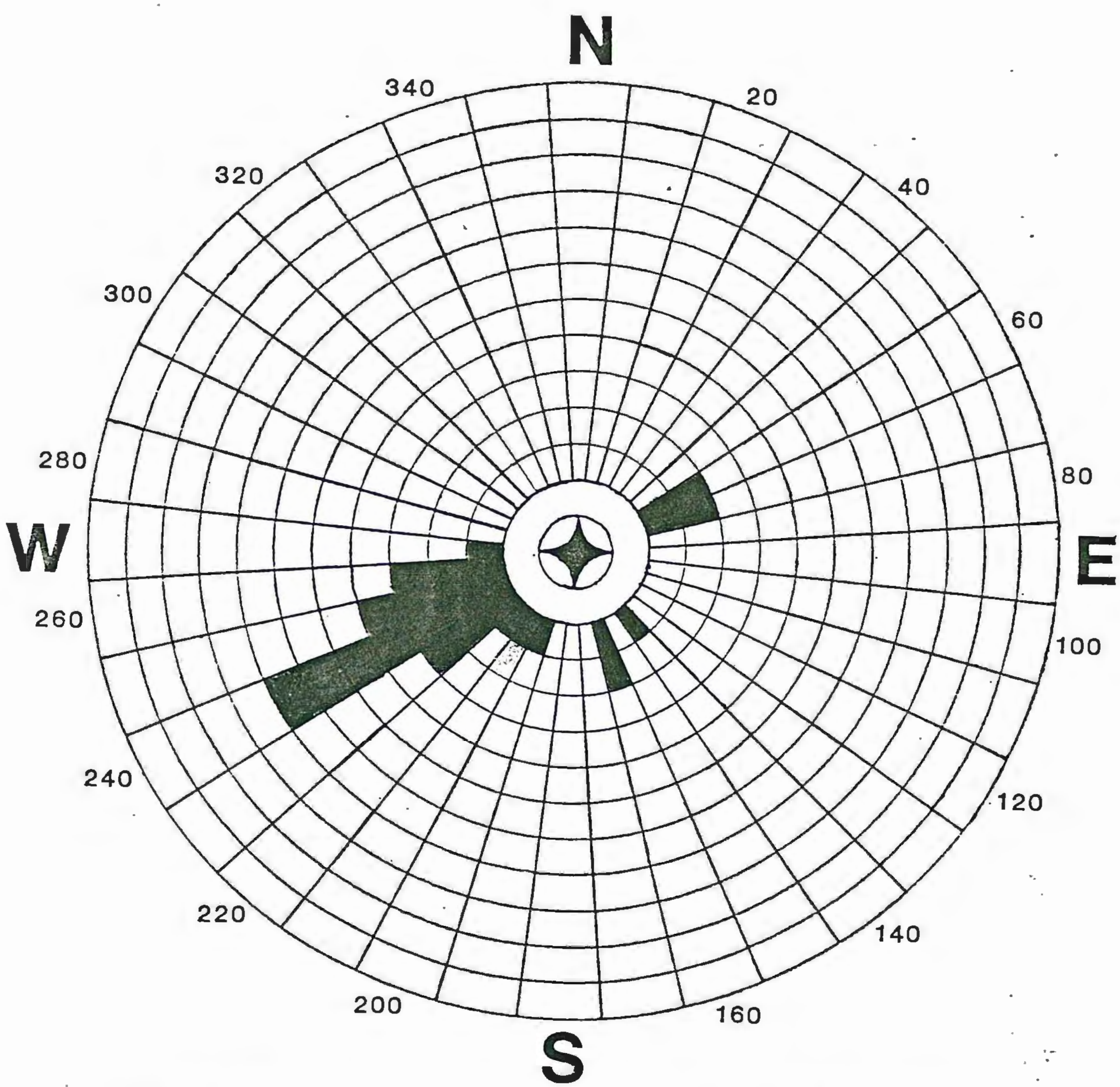

Figure 6.8a Paleocurrent rose diagram for trough cross-bedding and planar cross-bedding measurements of the Mine Centre area corrected for simple tilt (n=28).

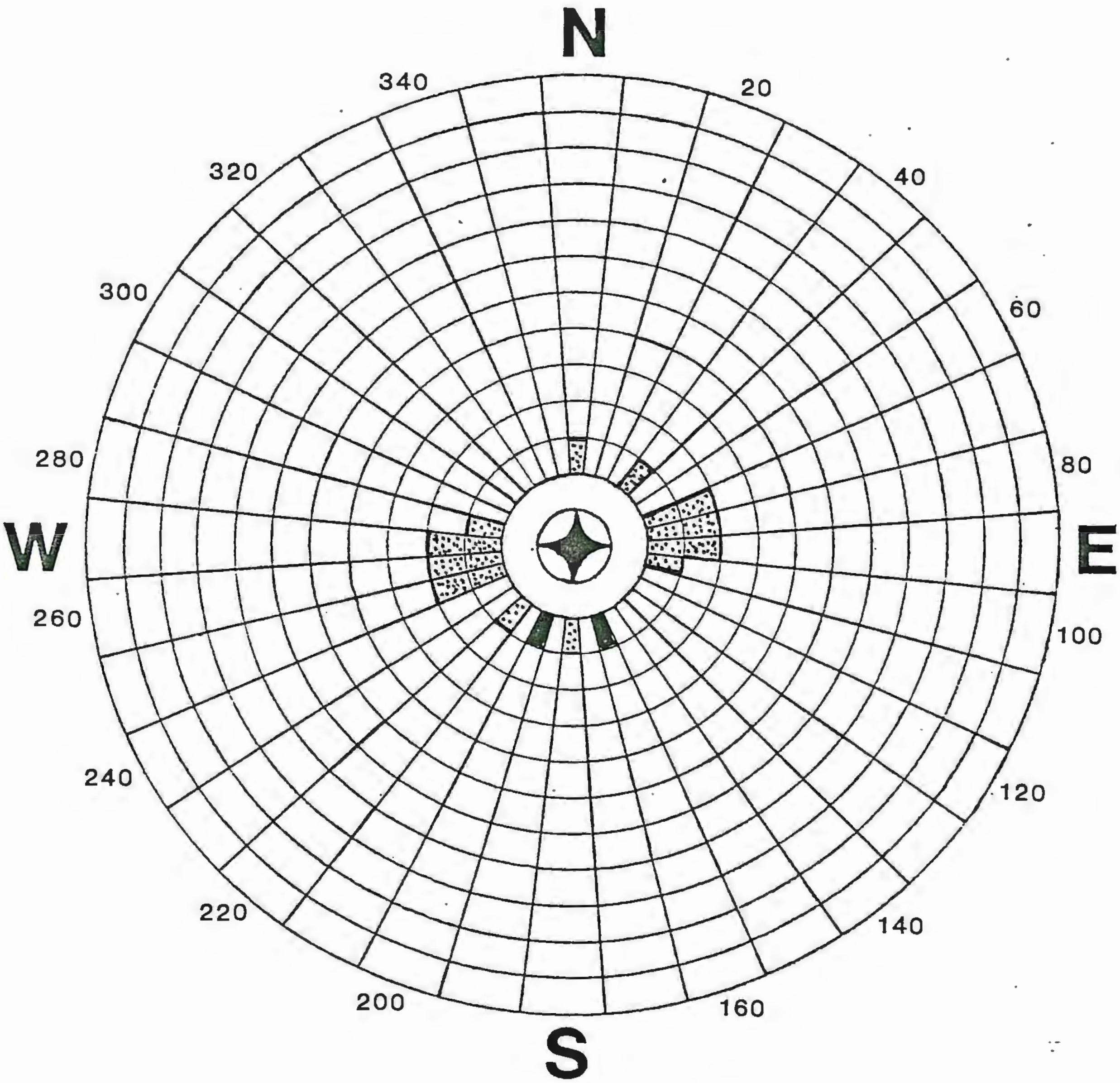

Figure 6.8b Paleocurrent rose diagrams for trough axes measurements of the Mine Centre area corrected for simple tilt (n=11). Stipled measurements are plotted bi-directionally.

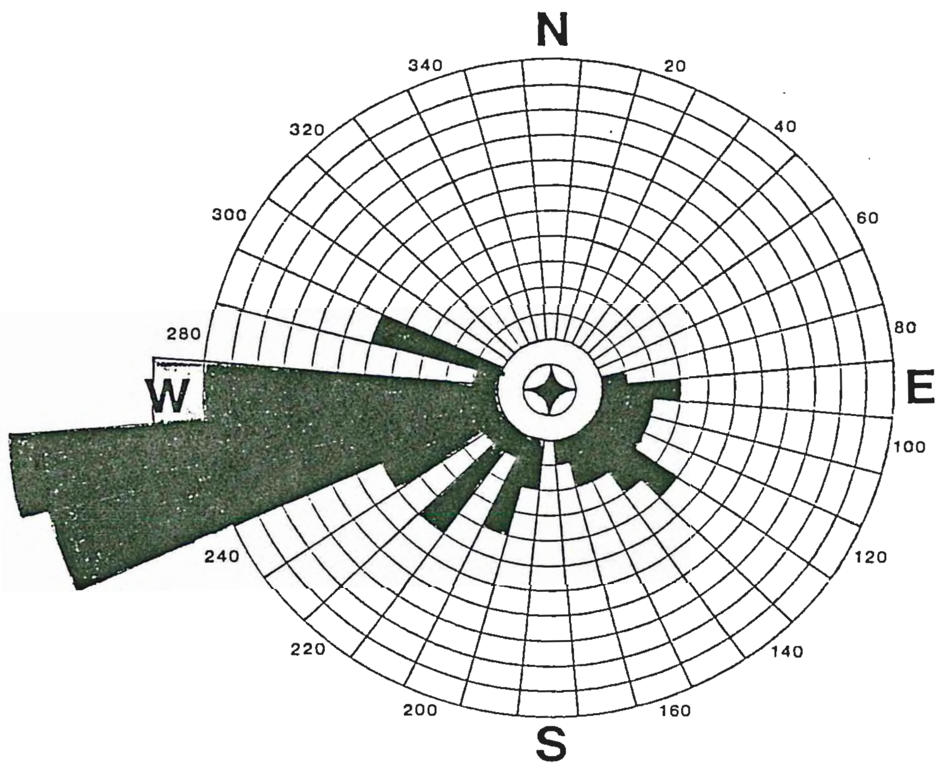

Figure 6.9a Paleocurrent rose diagrams for trough cross-bedding and planar cross-bedding measurements of the Rainy Lake island area, including Dryweed, Grindstone, and Big American islands, and part of Neil Point, corrected for simple tilt (n=97).

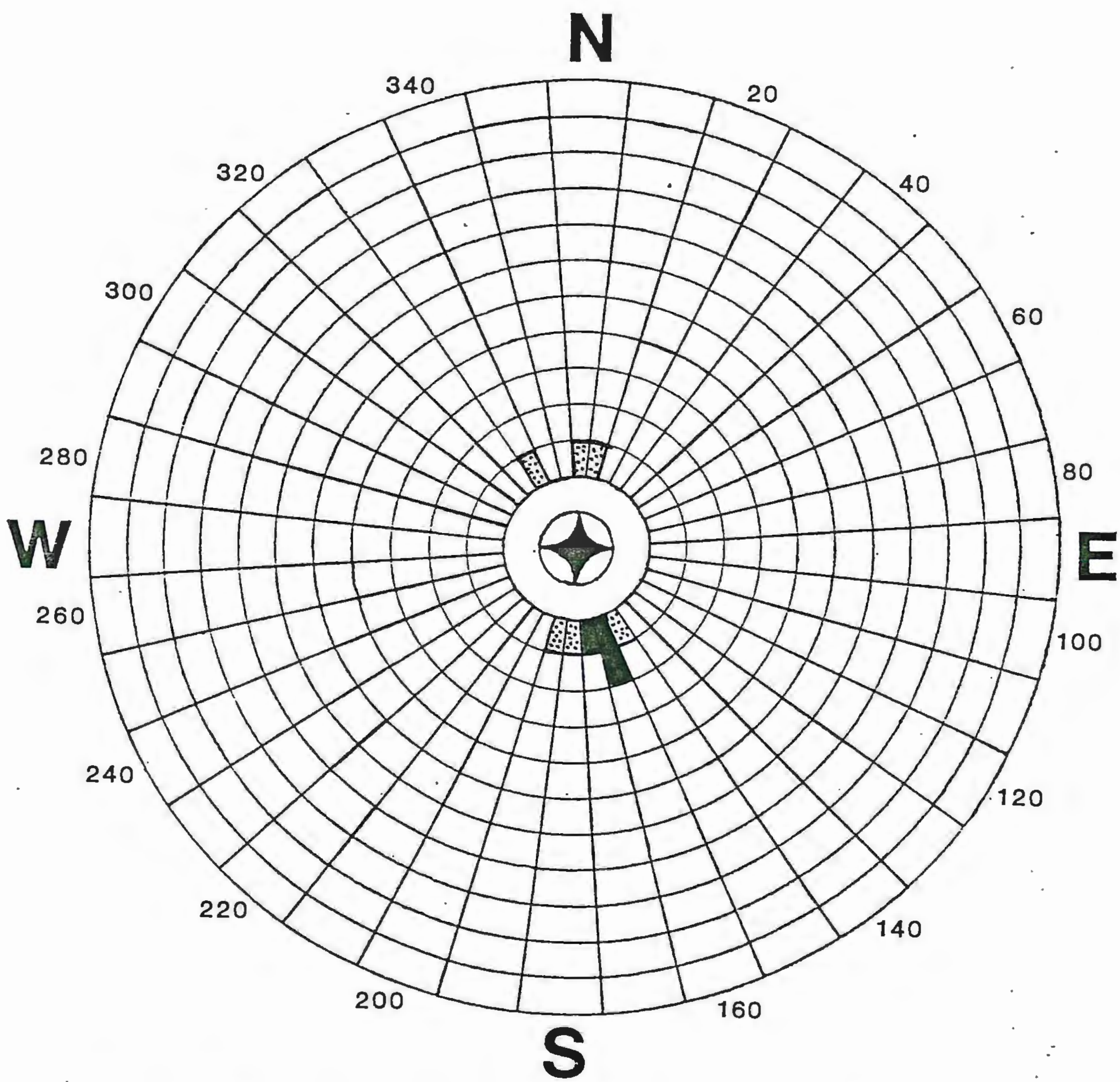

Figure 6.9b Paleocurrent rose diagram for trough axis measurements of the Rainy Lake island area corrected for one simple tilt (n=6).

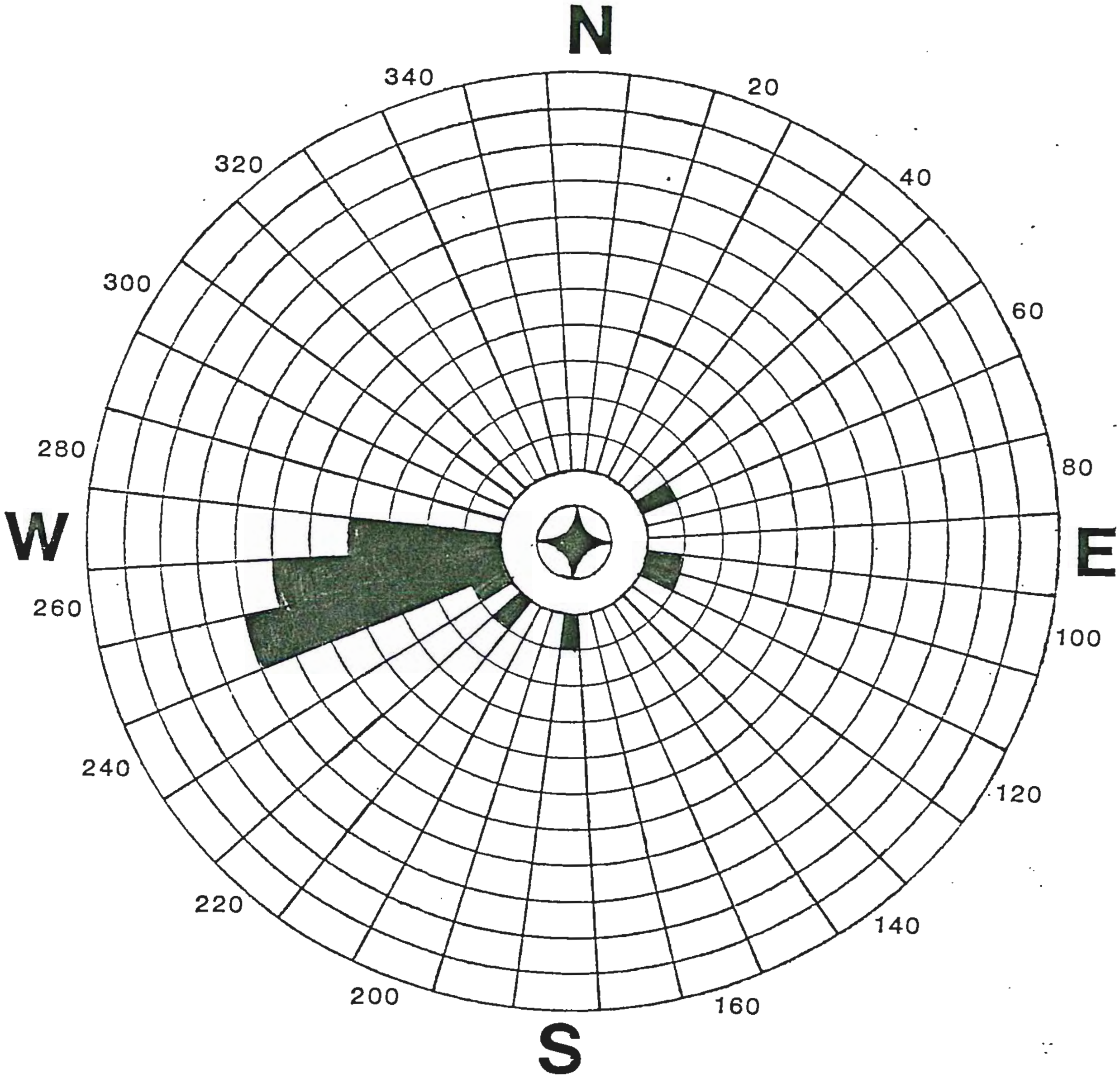

Figure 6.10a Paleocurrent rose diagram for trough cross-bedding and planar cross-bedding of the western Rainy Lake area, including the area near County Road 11 southeast of Ranier, MN. corrected for simple tilt (n=23).

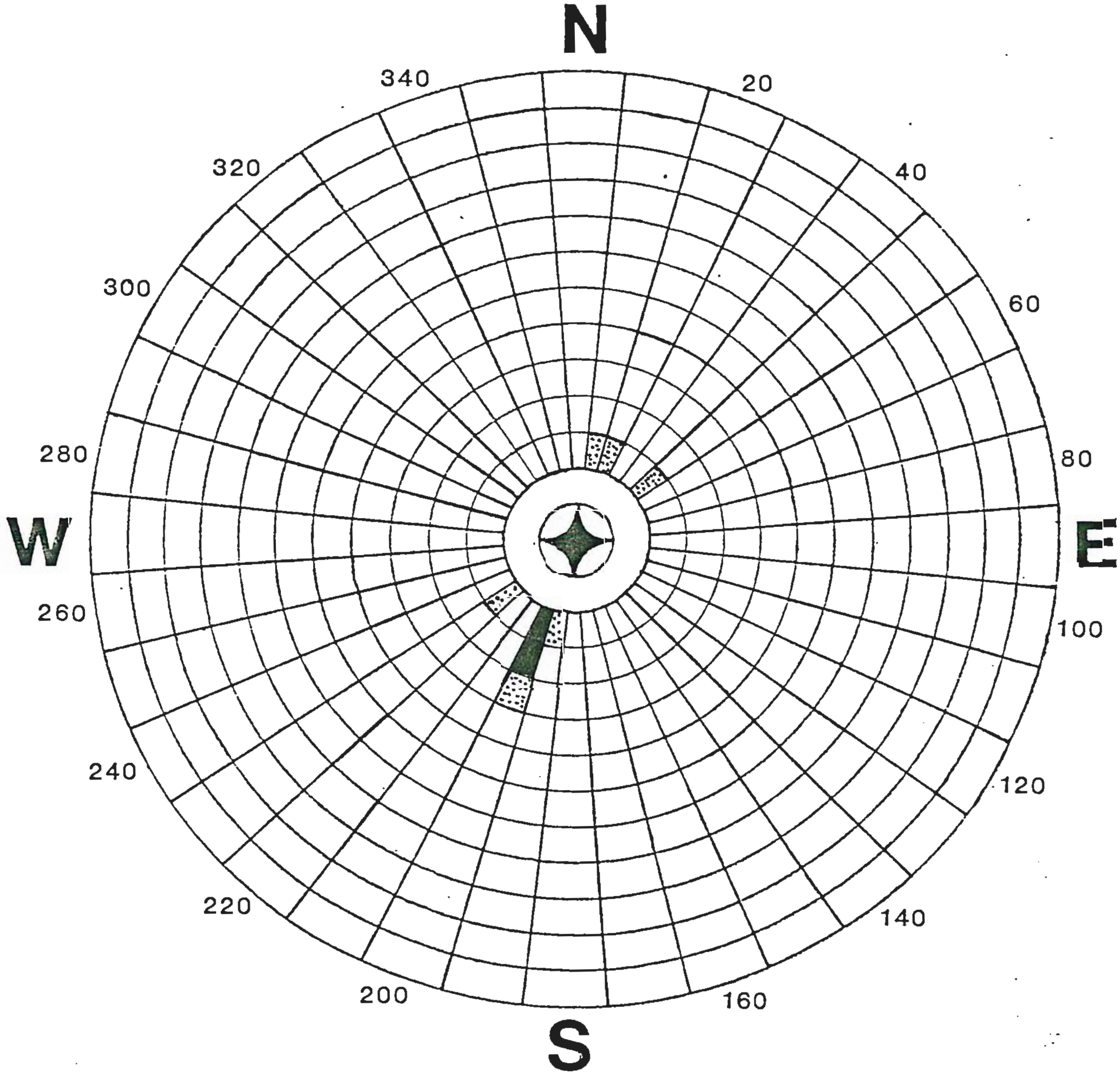

Figure 6.10b Paleocurrent rose diagram of trough axes measurements for the western Rainy Lake area corrected for simple tilt (n=6).

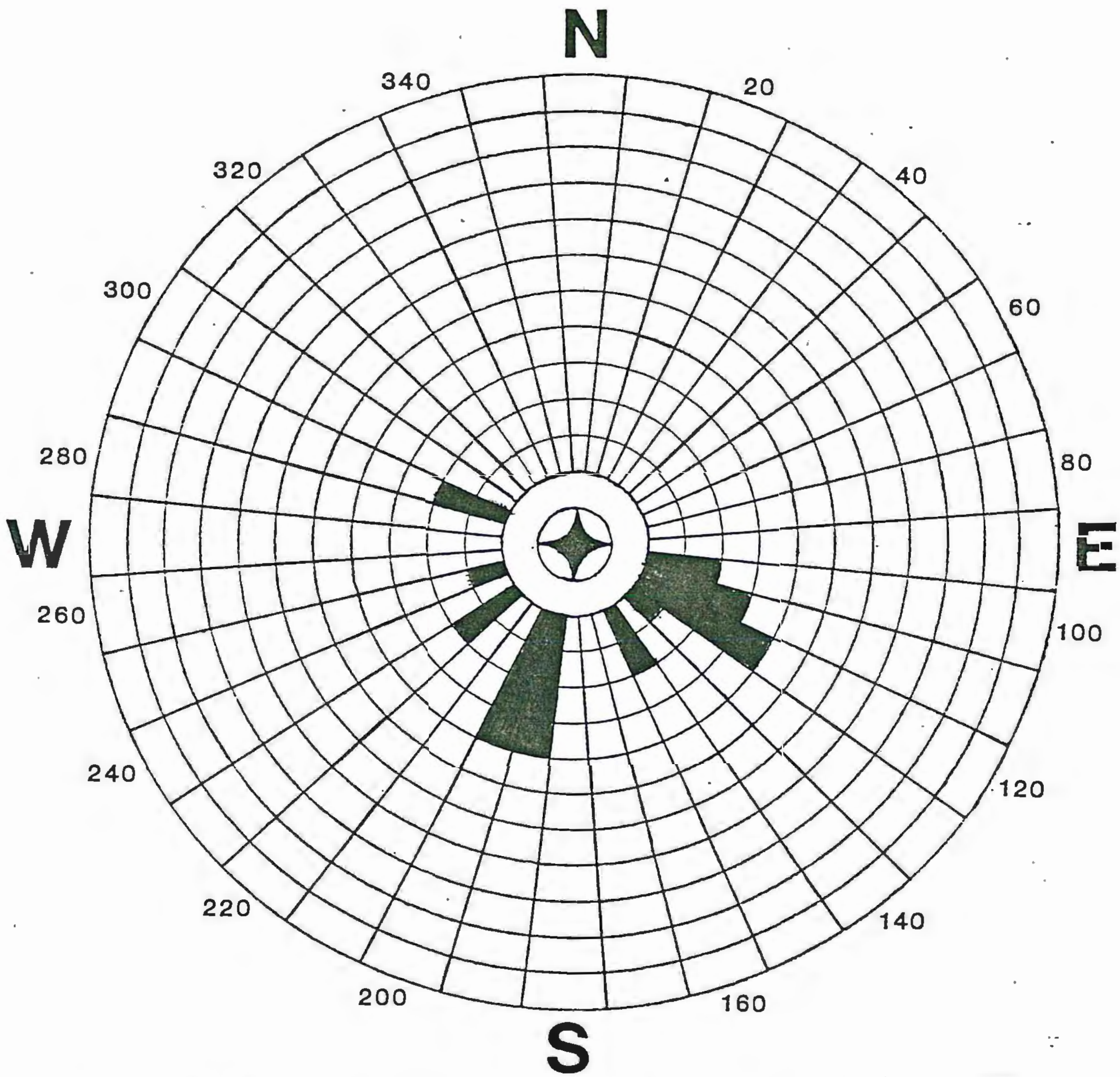

Figure 6.11a Paleocurrent rose diagram of trough cross-bedding and planar cross-bedding measurements for the Mine Centre area, sandstone Unit 3, corrected for tilt and plunge (n=28).

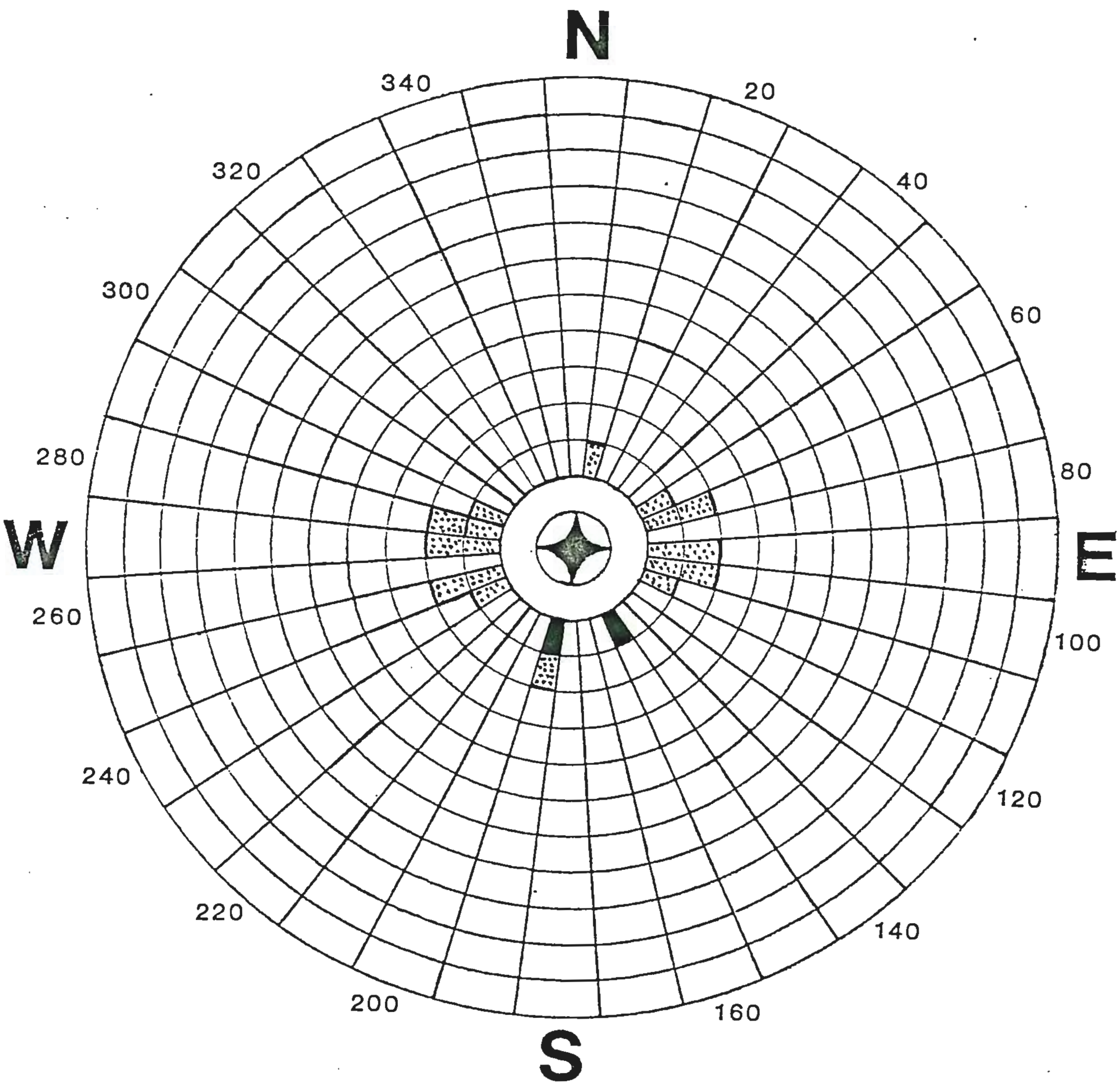

Figure 6.11b Paleocurrent rose diagram of trough axes measurements for the Mine Centre area corrected for tilt and plunge (n=11).

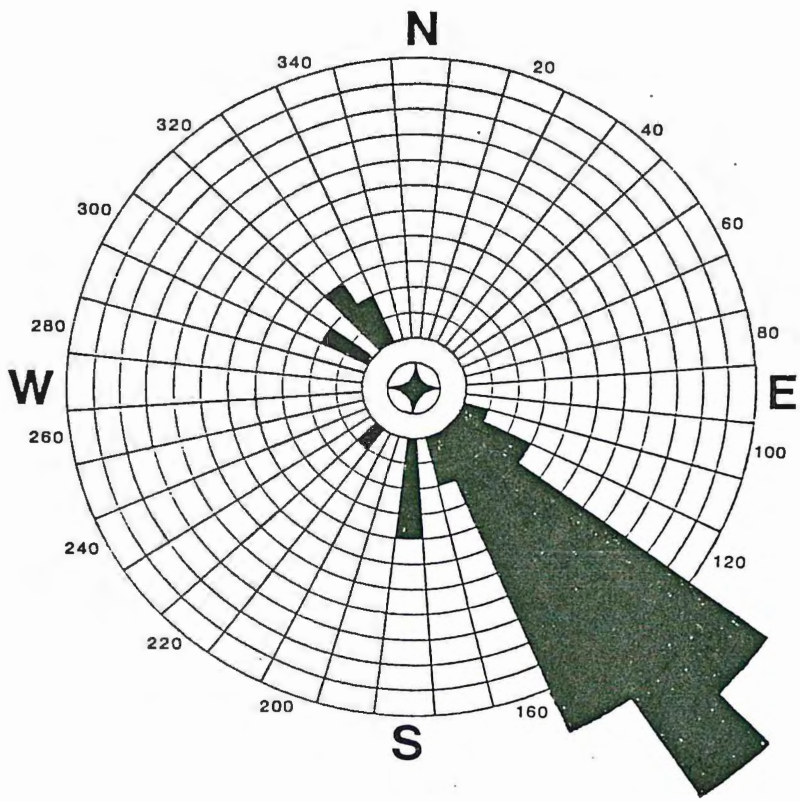

Figure 6.12a Paleocurrent rose diagram for trough cross-bedding and planar cross-bedding measurements of the Rainy Lake Island area corrected for tilt and plunge (n=65).

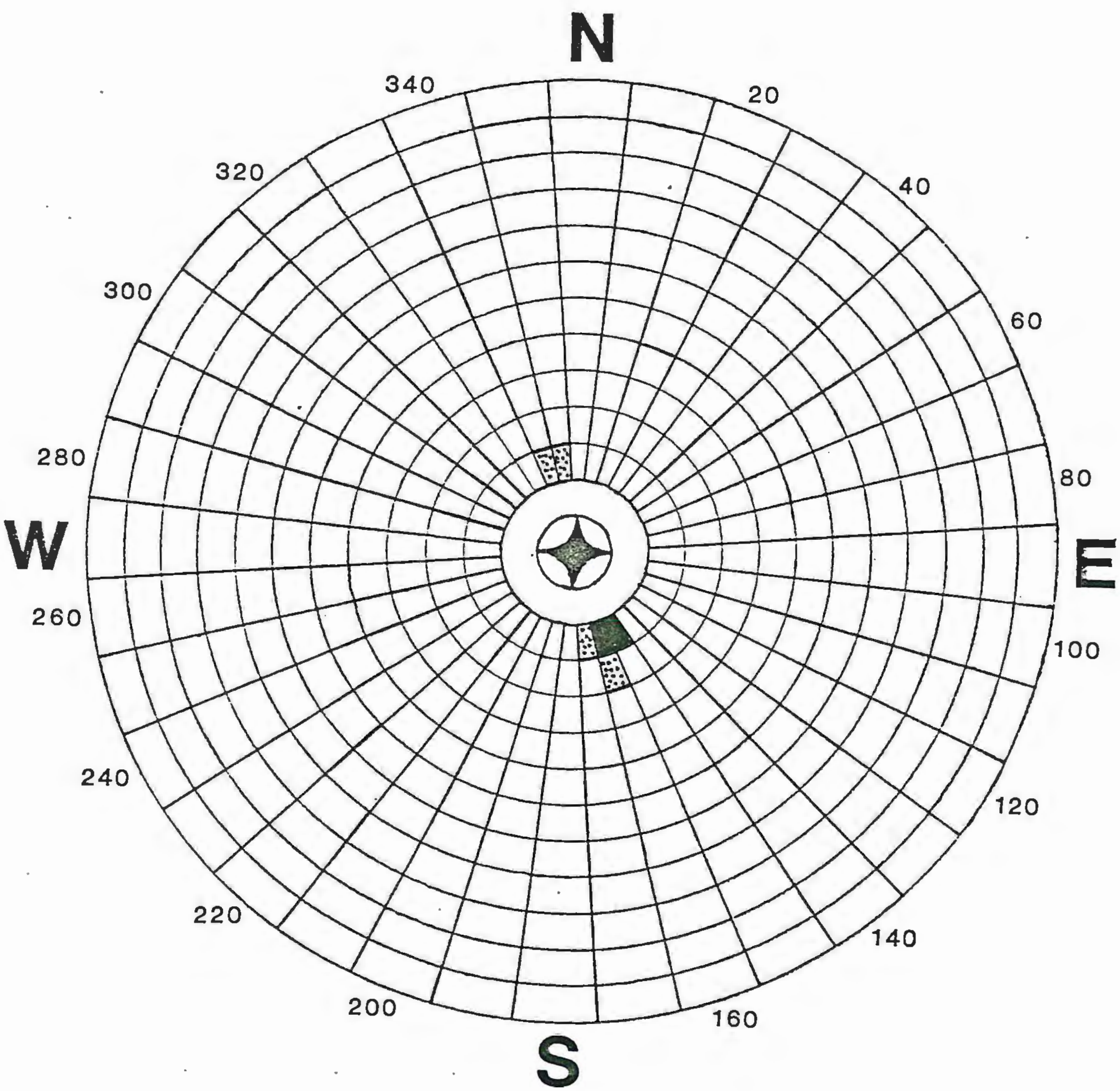

Figure 6.12b Paleocurrent rose diagram of trough axes measurements for the Rainy Lake island area corrected for two rotations (n=4).

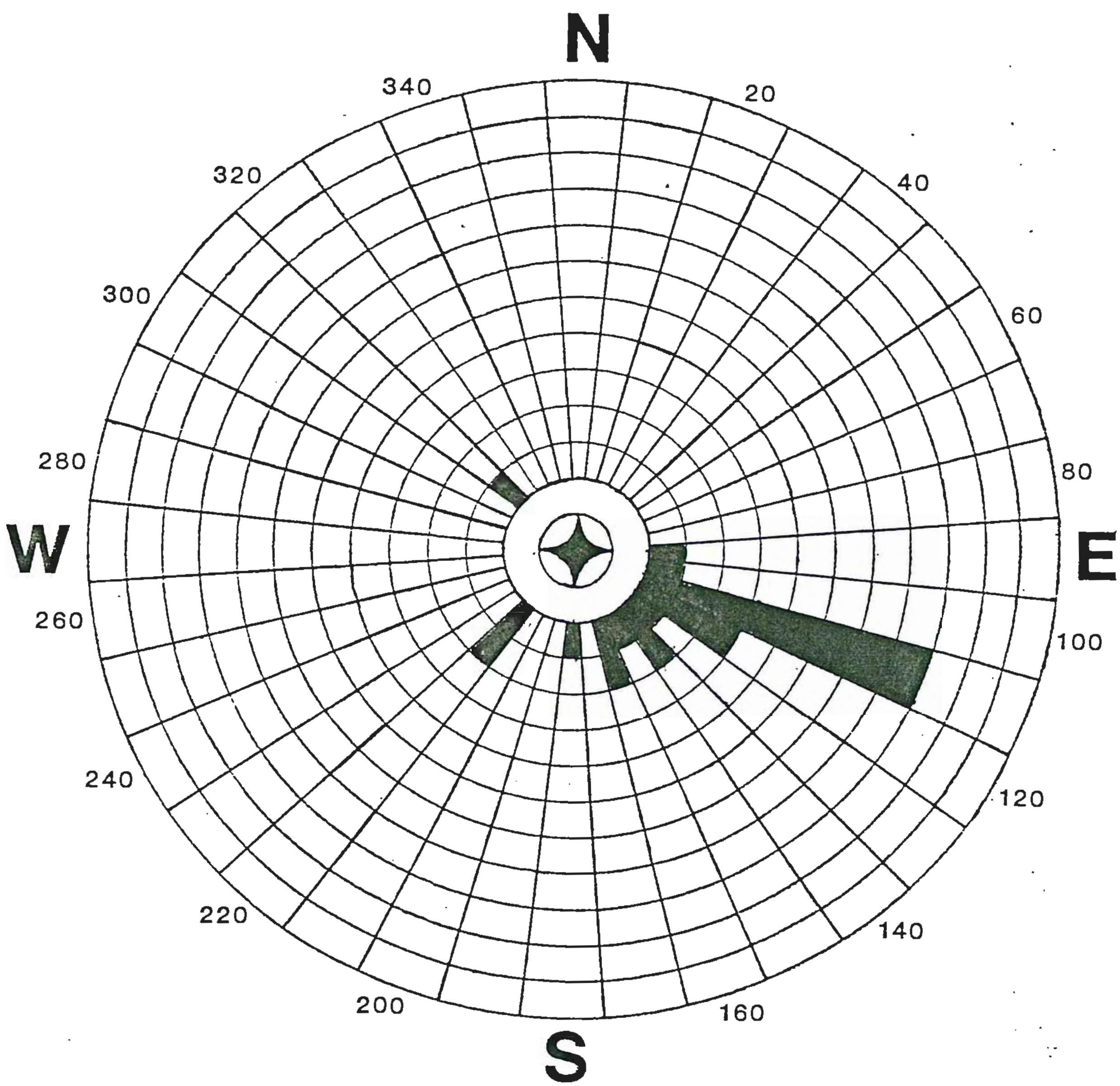

Figure 6.13a Paleocurrent rose diagram of trough cross-bedding and planar cross-bedding measurements for the western Rainy Lake area corrected for tilt and plunge (n=23).

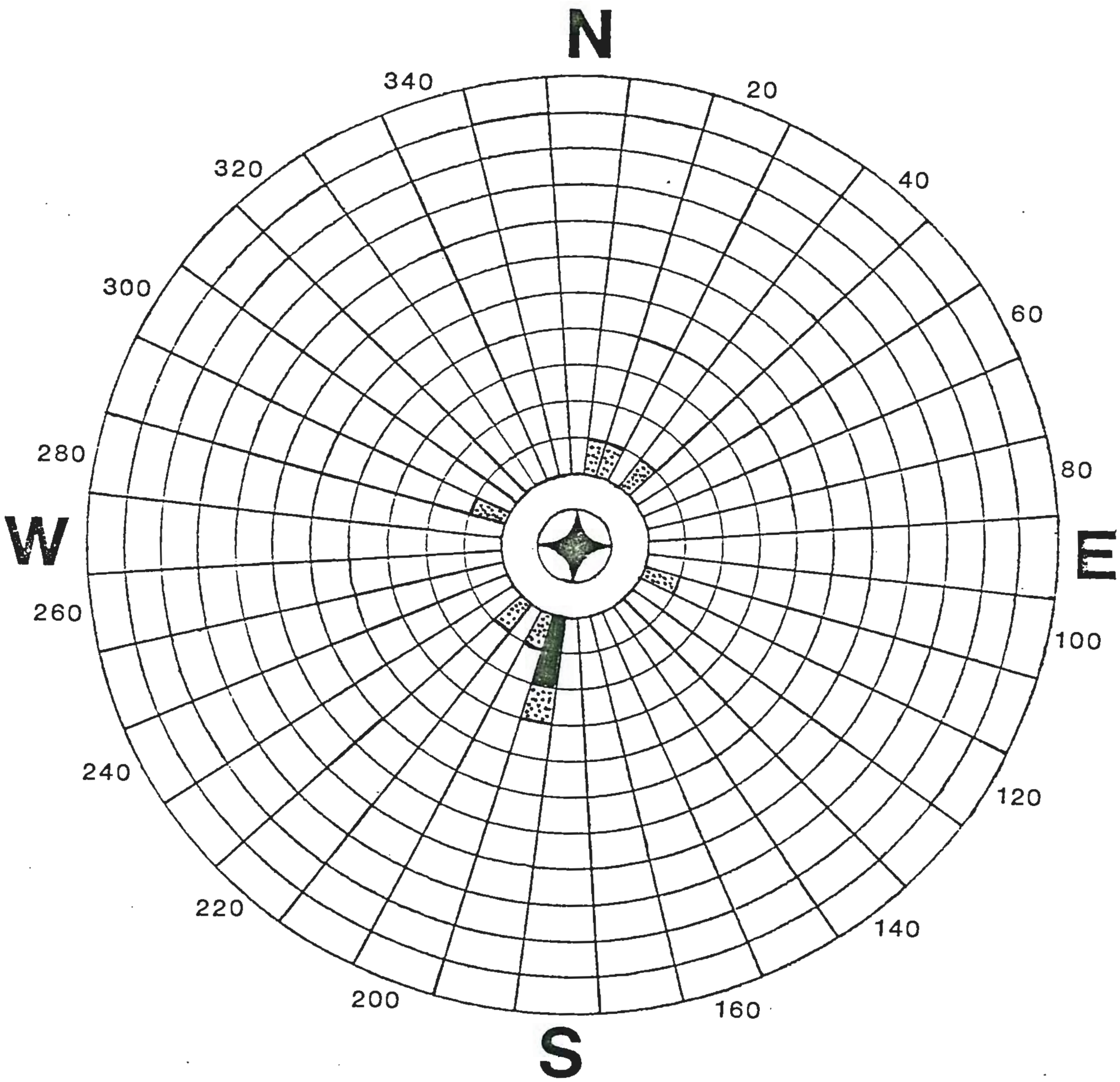

Figure 6.13b Paleocurrent rose diagram of trough axes measurements for the western Rainy Lake area corrected for tilt and plunge (n=6).

Figure 6.11 a and b, 6.12a and b, and 6.13a and b are the results from correcting for two rotations (for a tilt and plunge). The second correction modifies the data for the western part of the study area to give a southeasterly mode. These results (shown in map layout in Figures 6.14 and 6.15), are in the same general southerly direction reported by Ojakangas and Olson (1982), who also corrected for both tilt and plunge.

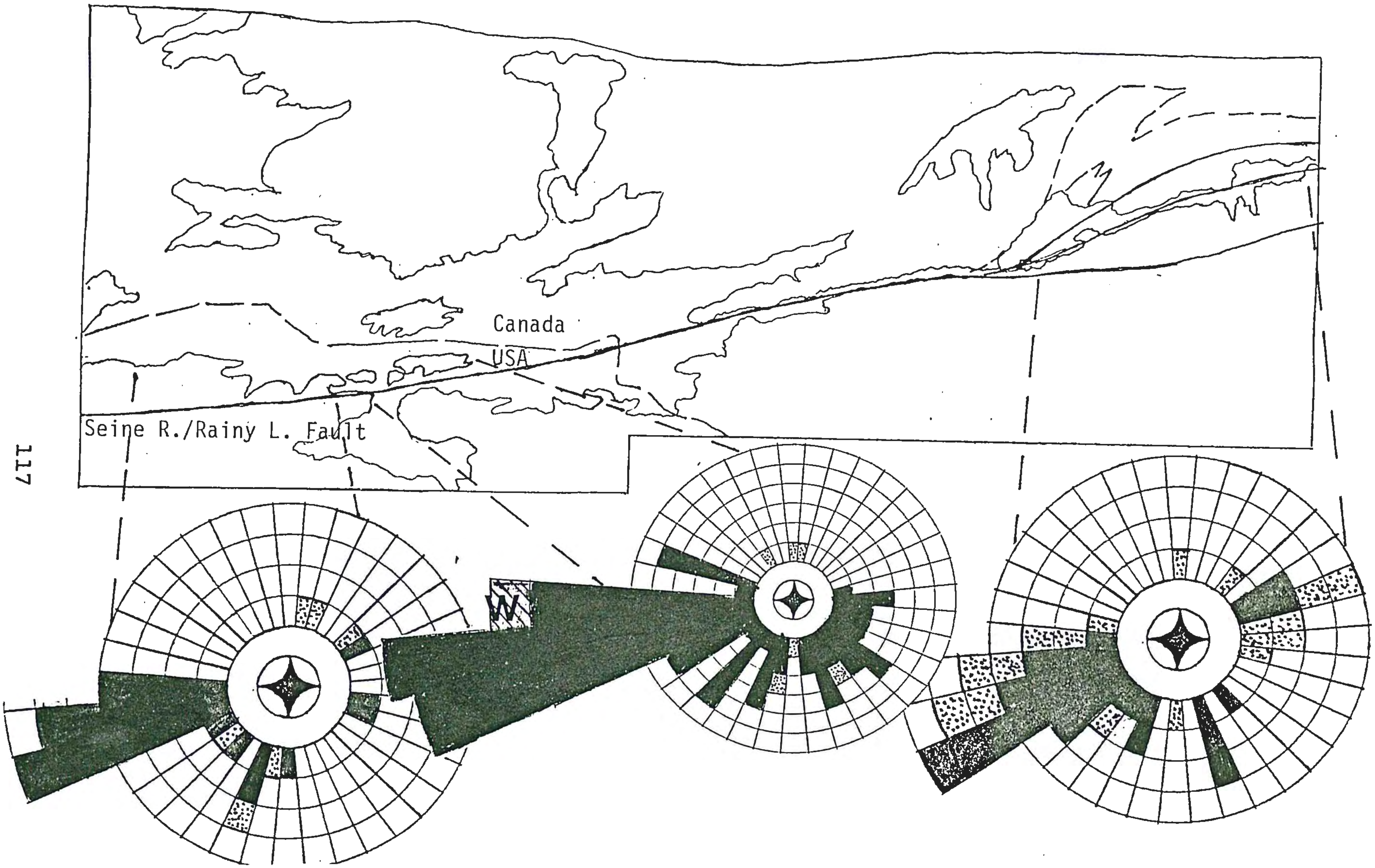

Figure 6.14 Results of paleocurrent measurements for the entire study area corrected for simple tilt. Trough cross-beds, planar cross-beds and trough axes measurements are combined for each rose diagram.

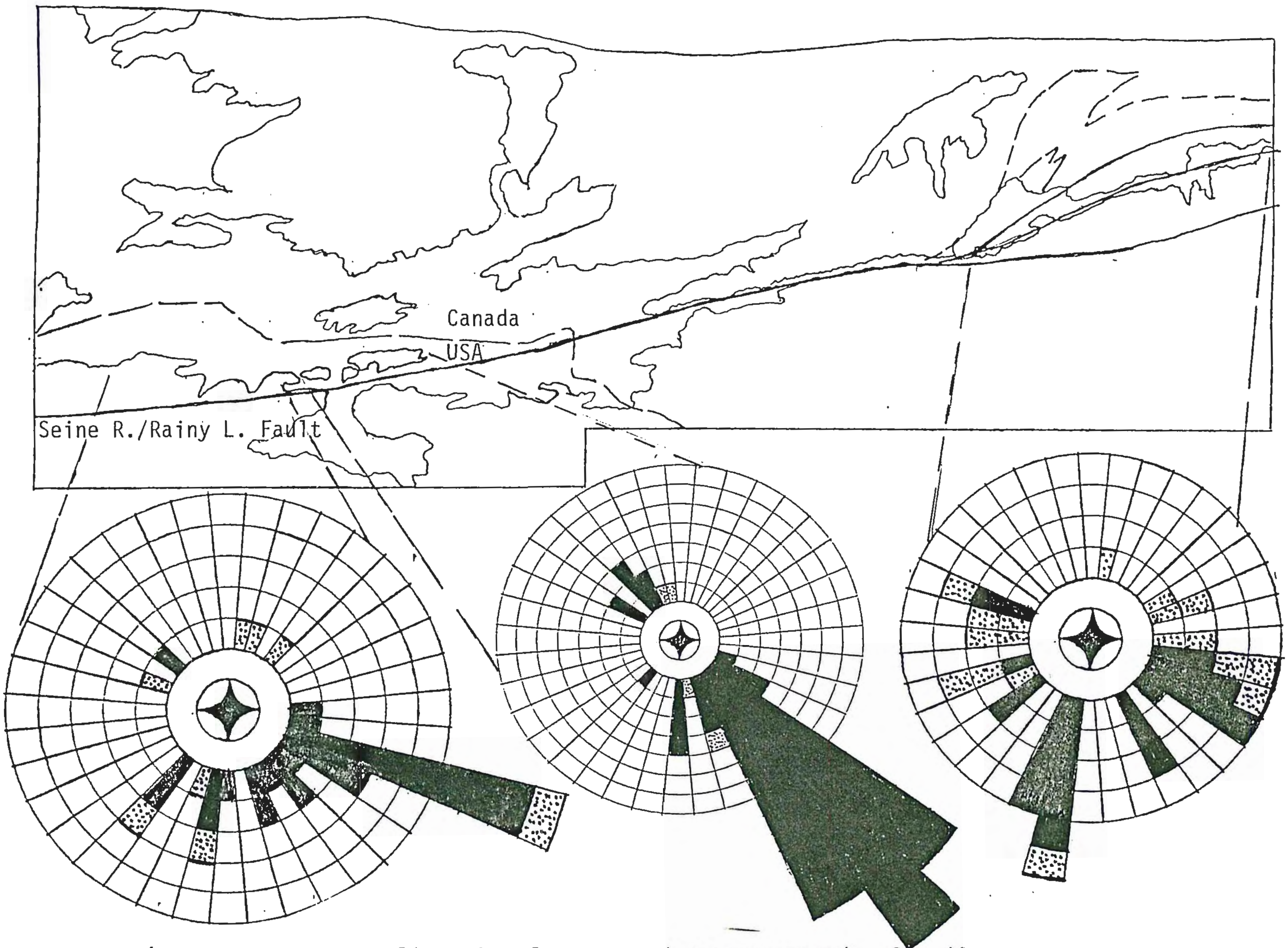

Figure 6.15 Results of paleocurrent measurements for the entire study area corrected for tilt and plunge. Trough cross-beds, planar cross-beds and trough axes measurements are combined for each rose diagram.

Chapter 7

PROVENANCE

Provenance of the Seine Group

The conglomerate exhibits a mixed provenance with various volcanic rocks and felsic plutonic rocks as the dominant sources. Other less important source rocks are greywacke, arkosic arenite, chert, and biotite schist.

The conglomerate north of Shoal Lake, Units 1 and 2, was deposited nonconformably upon the tonalite. Megascopic modal analyses indicate that Units 1 and 2 are derived from the Bad Vermillion Lake pluton and nearby volcanic rocks which are mostly of felsic to intermediate types as shown in Figure 3.7. Thin section modal analyses of the "conglomerate-matrix" suggest that the grains were derived from volcanic terranes, mostly felsic to intermediate, but with some minor mafic rocks also present; the abundant quartz and plagioclase most likely are of plutonic origin.

Unit 5, the polymict orthoconglomerate overlying the feldspathic sandstone on Neil Point, is a higher stratigraphic unit. Modal analyses show a greater average percentage of tonalitic cobbles than the eastern units 1 and 2; felsic dacitic volcanic clasts still dominate. Minor sedimentary-derived clasts are present in this unit, as in Units 1 and 2 of the eastern part of the study area. The "conglomerate-matrix" in this area is sandy and modal analyses averages 53% rock fragments (mostly felsic volcanic), 16% feldspar, and 16% quartz. Sand-sized rock fragments are mostly of volcanic derivation, with minor plutonic and sedimentary grains. Figure 4.10 shows a feldspathic sandstone fragment which has the same appearance and composition as the feldspathic sandstones of the Seine Group. The pebbly sand interbeds are made up of 45% rock fragments with 18% feldspar and 20% quartz. Modal analyses show that the pebbles, cobbles, and boulders, the sandy matrix, and the pebbly sandstone interbeds in the conglomerate units have similar compositions and the same sources. Interbeds average 20% matrix and are classified as feldspathic greywacke using Dott's (1964) classification.

The feldspathic sandstone, Units 3 and 4, exhibits a mixed provenance with various volcanic rocks as the dominant sources. Quartz, plagioclase and rock fragments dominate while less dominant constituents include mafic dike rock fragments, chert, biotite, epidote, muscovite, chlorite, pyrite, iron carbonate, and limonite. The high quartz content of the feldspathic sandstone, 50% or more, was probably derived from the quartz-rich plutonic rocks.

In the eastern part of the area, the feldspathic sandstone (unit 3) is found to average more than 55% quartz in the lower parts while the finer-grained, silt-rich upper part contains approximately 35% quartz. Staining for feldspar shows a content of 25-44% plagioclase and less than 5% alkali feldspar.

In the western part of the area, Unit 4, which is the correlative sandstone, averages 48% framework quartz, 15% feldspar and 14% rock fragments. These feldspathic sandstones are much less deformed than Unit 3 in the eastern part of the study area. The average quartz content of feldspathic sandstones in the west is 51% including the matrix component. This quartz content of the feldspathic sandstones (of greater than 50%) is much greater than the quartz content of the conglomerate-matrix and the sandstone interbeds of the conglomerates.

The volcanic rocks of the district show a bimodal pattern of basalt and rhyodacite compositions (Goldich and Peterman, 1980). Goldich and Peterman recognized some tuffaceous rocks that may be of intermediate composition. Their data, shown in Figure 7.1, suggest an iron enrichment, in contrast with the average of Archean volcanic rocks as defined by Baragar and Goodwin (1969). Poulsen (1984) interpreted the felsic metavolcanics to have formed relatively more distant from a volcanic center than the mafic rocks near Mine Centre.

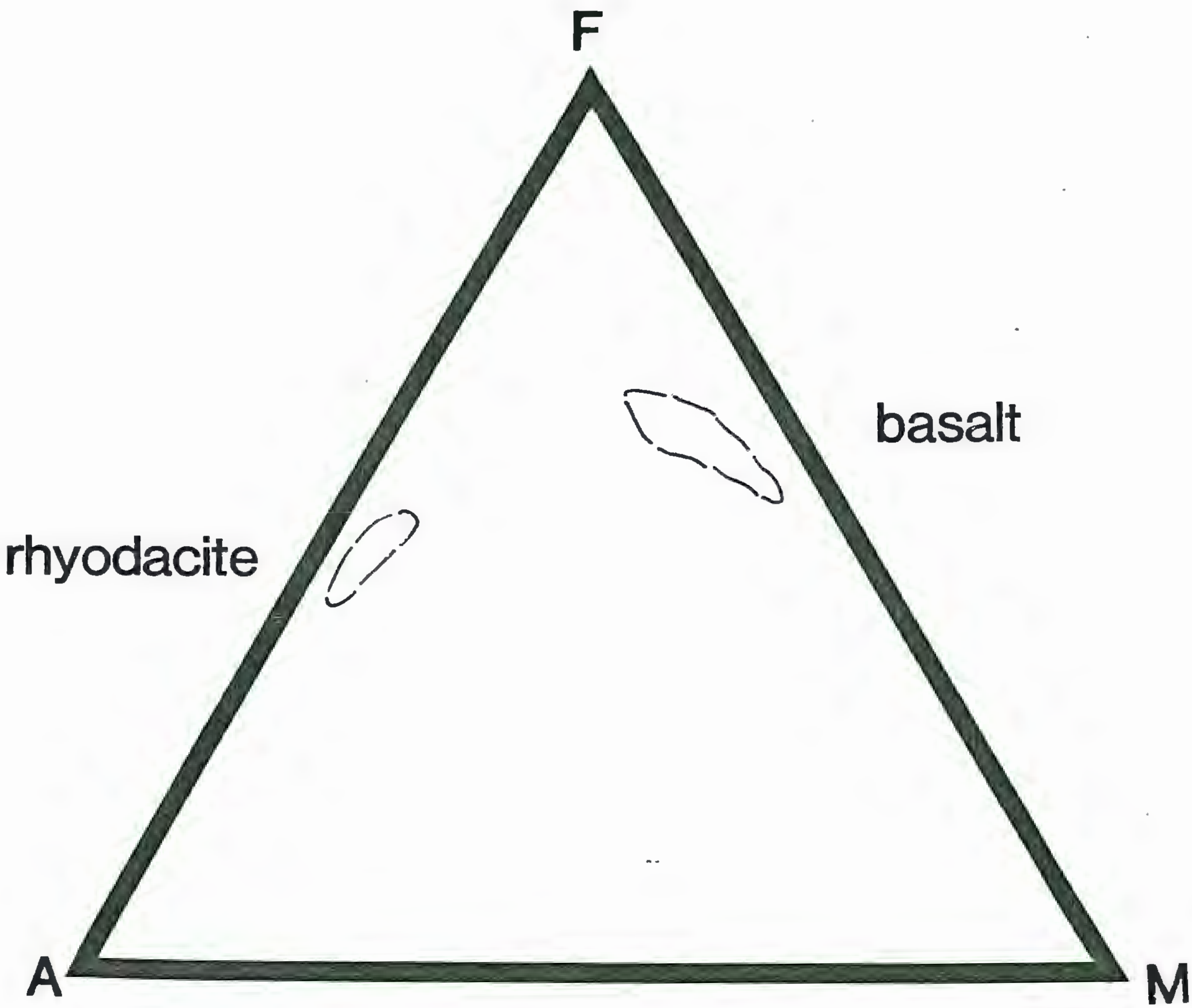

Figure 7.1 AFM diagram showing data for Archean volcanic rocks of the Rainy Lake-Mine Centre area (From Goldich and Peterman, 1980).

Other rock fragments in the "conglomerate-matrix," such as biotite schist and arkosic arenite, suggest sedimentary and metasedimentary sources such as metagreywacke, chert, and arenite. Although the sandstone grain (Figure 4.10) is identical to the arkosic arenite, it is not interpreted as an intraformational clast because it was deposited as a lithified fragment while the Seine Group was most likely not lithified at that time.

Tonalitic rock fragments of granule to sand-size are not as abundant as are tonalitic cobbles and boulders in the coarser fractions. The low percentage of alkali feldspar in the feldspathic sandstones is noteworthy. The Grassy Island Tonalite is a low-potassium rock (e.g., Cram, 1932). The average alkali feldspar present in the tonalite is 0-5% while the average present in the feldspathic sandstone is less than 1%. Table 4.1 shows that thin section analyses and staining of pebbles of tonalite and the tonalite intrusions contain an average alkali feldspar content of 0-3% while the average in the feldspathic sandstone is less than 1%. Most of the alkali feldspar grains appear to be sanidine or orthoclase, and are usually untwinned.

According to field analyses, the tonalitic cobbles of Units 1 and 2 in the eastern part of the study area range from 0-3 % alkali feldspar. The tonalitic cobbles in Unit

5 in the western part of the study area range from 0-5% alkali feldspar. Thurston and others (1985) suggested that large compositionally zoned chambers with basaltic liquid acted as long term heat sources. Their emplacement may have caused melting of more sialic crust to produce felsic magma. As Goldich and others (1961) presented, no felsic plutonic source other than the Grassy Island Tonalite is proposed for Unit 5, and no felsic plutonic source other than the Bad Vermillion Lake pluton is proposed for Units 1 and 2. In the western part of the study area, felsic plutonic cobbles collected from Unit 5 on Neil Point and to the west may be attributed to the Grassy Island Tonalite. Of course, similar tonalitic clasts may have been derived from other plutons, now unexposed, which intruded at about the same time as the Grassy Island Tonalite and had a similar composition.

The biotite schist clasts (shown in Figure 4.11), which have a schistosity at an oblique angle to the foliation throughout the conglomerate, are attributed to the metasedimentary units such as the Coutchiching. The chemical compositions of the biotite schist of the Superior Province indicate that they were derived from a basalt-rhyodacite volcanic pile and volcanic rocks of these compositions are present in the Rainy Lake area. Ayres (1983) reported that petrographic and chemical evivdence support derivation of greywacke and siltstone from a rhyolite or rhyodacite provenance. Ojakangas (1985) reviewed chemical analyses of metasediments and showed a striking similarity to rhyodacites and dacites. The abundance of volcanic detritus, especially felsic, suggests a major volcanic source involving the rapid reworking of detritus, perhaps unconsolidated. Ojakangas (1985) suggests that subordinate felsic plutonic detritus of the greenstone belts and perhaps of the metasedimentary belts were mainly derived from synvolcanic plutons, with some perhaps from sialic basement. Thurston and others (1985) reported that many greenstone belts contain voluminous greywacke-siltstone sequences that are associated with less voluminous felsic metavolcanics.

The iron-formation clasts are present in Units 1 and 2 in the eastern area. The iron-formation cobbles and chert cobbles have been attributed to older chemical sedimentary units.

Dickinson and others (1983) showed that triangular QFL and QmFLt diagrams of framework modes of terrigenous sandstones show the type of provenance terrane controlled by plate tectonics. Three main classes of provenance are called "continental blocks," "magmatic arcs," and "recycled orogens." For the QFL plot the vertices are Q: total quartzose grains including polycrystalline composite quartz and chert fragments, F: monocrystalline feldspar grains, and L: unstable polycrystalline lithic fragments of igneous, sedimentary or metamorphic origins. Figure 7.2 shows the subdivisions for the QFL plot after Dickinson and Suczek (1979).

For the QmFLt diagrams, the apices are Qm: quartz grains that are defined as common quartz (more than 50% of a grain monocrystalline), F: as before, and Lt: total lithic fragments with quartzose varieties including chert and polycrystalline composite quartz. Figure 7.2 also shows the QmFLt diagram and the provisional subdivisions after Dickinson and Suczek. They noted however, that the positions of the individual boundary lines are empirical.

Discussion

Dickinson and others (1983) noted that the recycled orogen provenance can be divided into three zones on the QmFLt plot, as shown in Figure 7.2. On the QFL plot they divided the magmatic arc provenance into three subdivisions from undissected to dissected. Diagenetic growth of interstitial matrix can affect framework constituents through processes of solution and replacement. It should be emphasized that these fields were defined on the basis of Phanerozoic plate tectonics.

Most of the feldspathic sandstone samples from the

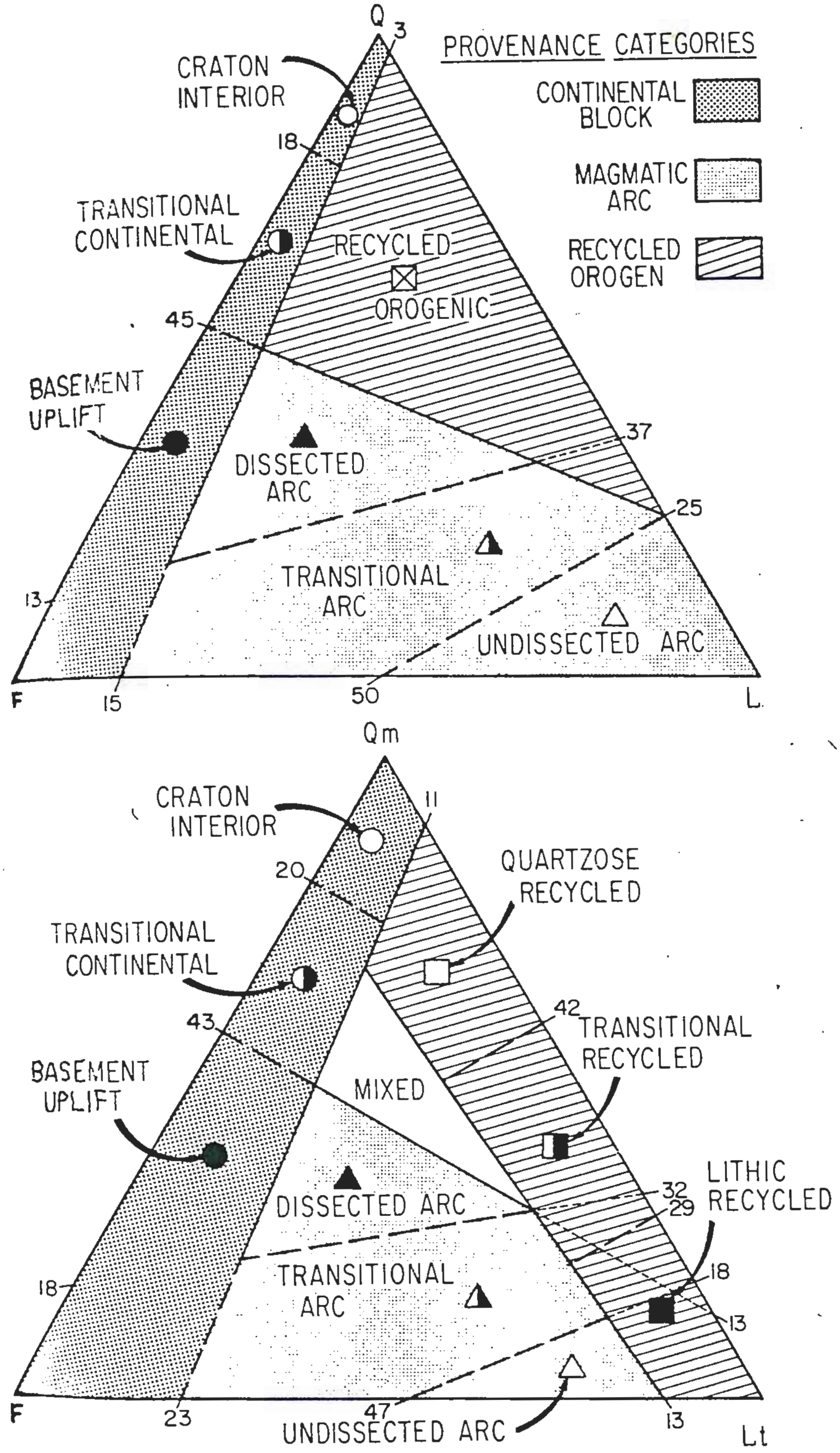

Figure 7.2 Subdivisions for the provenance zones of the QFL plot and the QmFLt plot (From Dickinson and Suczek, 1982).

western part of the area where Unit 3 is less deformed plot in the recycled orogen field on the QFL ternary diagram, as shown in Figure 7.3. Two samples plot near the boundary but in the continental block field.

On the QmFLt diagram (Figure 7.4) the feldspathic sandstone samples plot in the mixed zone near the border of the dissected arc field of the magmatic arc provenance. One sample plots just over the boundary in the recycled orogen field and one sample plotted in the magmatic arc field. Analysis of an individual feldspathic sandstone pebble in the conglomerate plots in the recycled orogenic provenance. Sedimentologic evidence such as the abundant volcanic and plutonic rock fragments and plagioclase grains suggests that a magmatic arc provenance may be more likely than a recycled orogen. The abundant quartz values that cause analyses to plot in the recycled orogen provenance may be additional quartz input from synvolcanic plutons.

The conglomerate-matrix samples plot in the undissected and transitional arc fields of the magmatic arc provenance in both the QFL and QmFLt diagrams. These samples plot in a much more immature zone, toward the lithic apex.

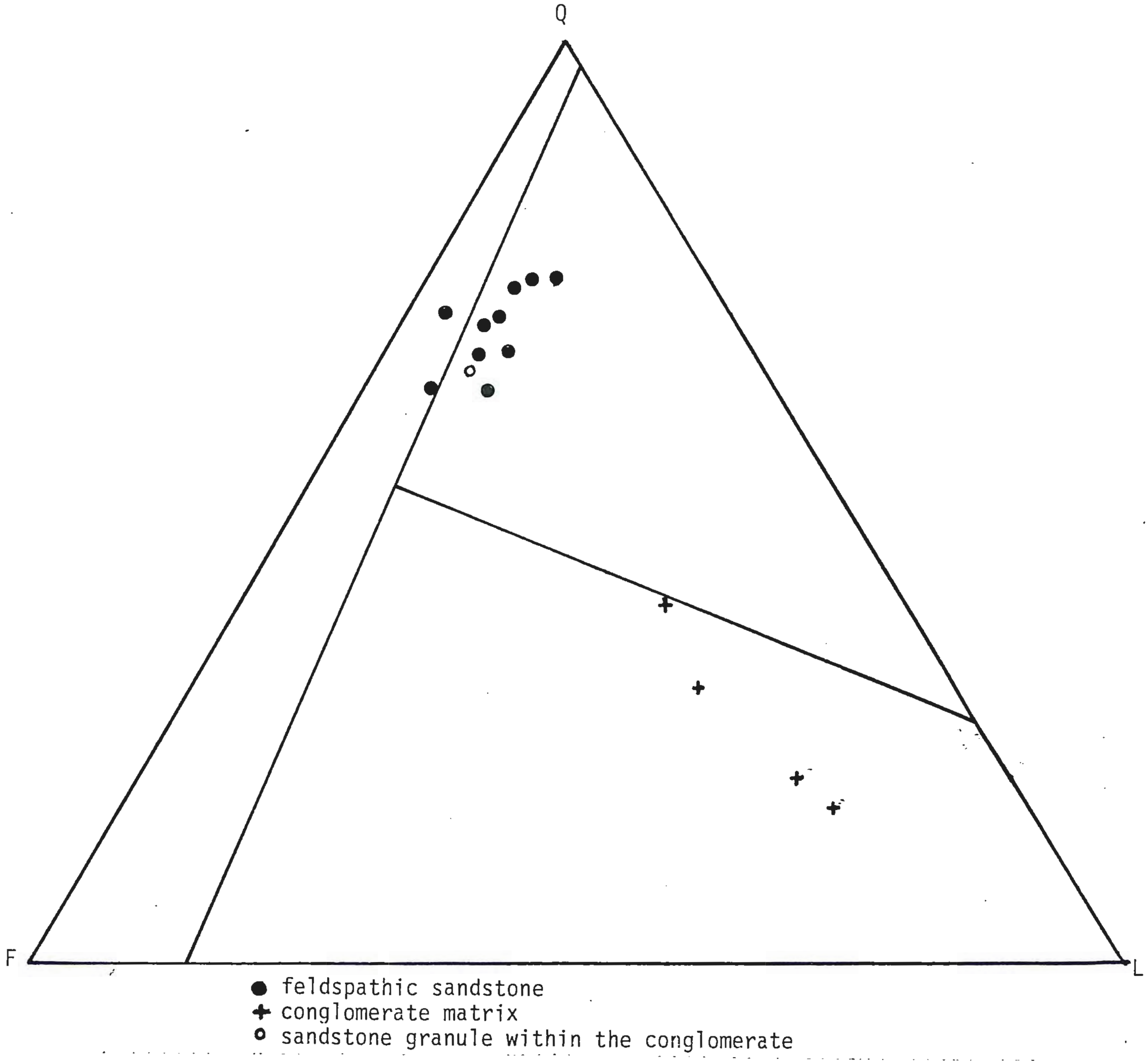

Figure 7.3 QFL plot for the Seine Group conglomerate and sandstone.

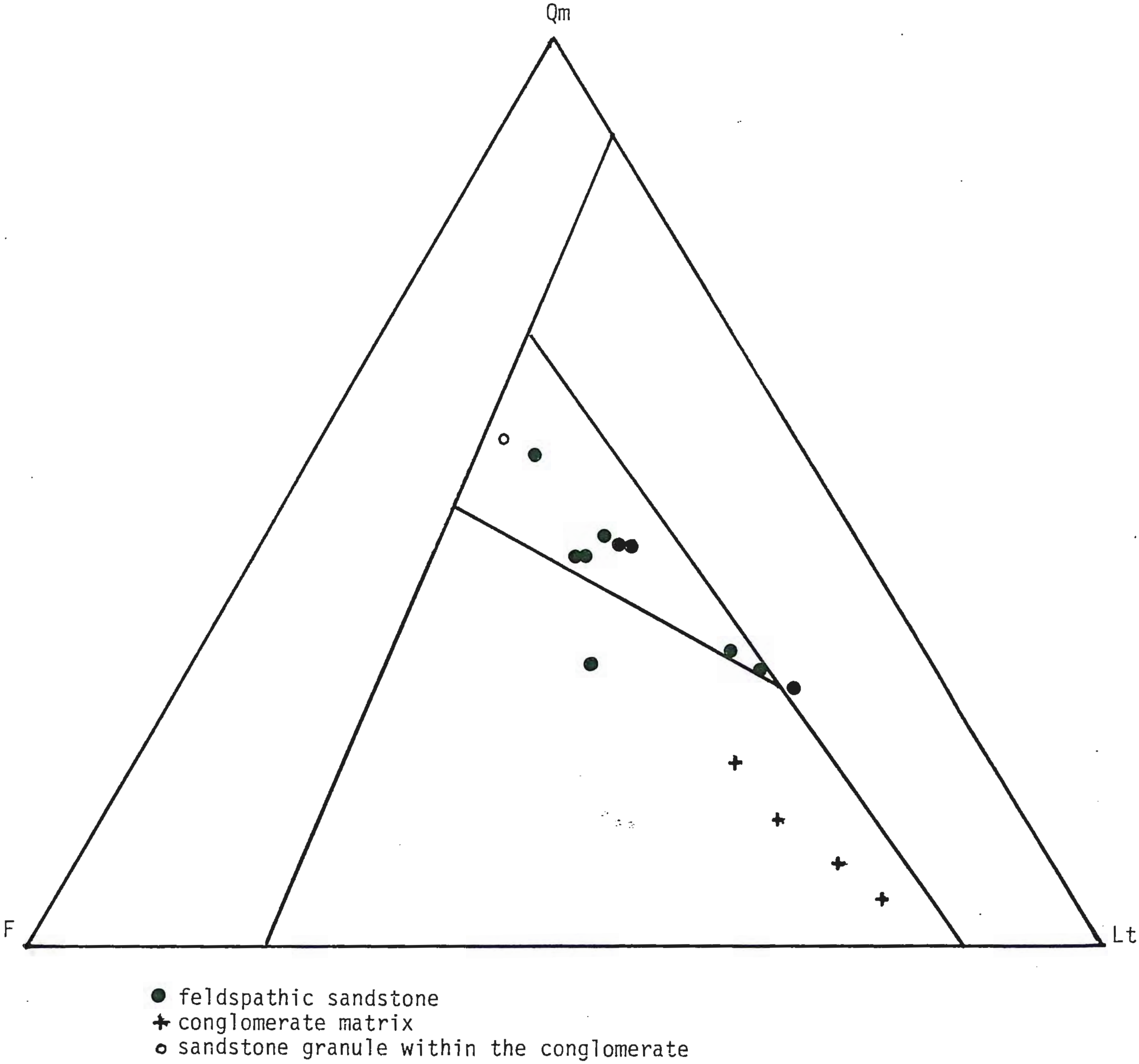

Figure 7.4 QmFLt plot for the Seine Group conglomerate and sandstone.

Chapter 8

GEOLOGIC HISTORY AND DEPOSITIONAL ENVIRONMENT

The Wabigoon Subprovince displays a diversity of sedimentary facies: submarine turbidite ramp and fan deposits, and alluvial and fluvial sequences. The common intercalation of facies suggests substantial topographic relief. The rocks of the Keewatin are the oldest recognized in the Rainy Lake District. The nature of the crust upon which these metavolcanic rocks were deposited is unknown. Whole sequences may represent mafic to felsic volcanic cycles with associated deposition of major volcanically derived sedimentary units during interludes in the volcanism. The similarity of the Archean volcanic sedimentary belts to modern day island arcs may suggest that the greenstones originated on a thin oceanic crust, the remnants of which were consumed. The framework components of the sandstone and conglomerates are variable, suggesting complex sources.

Termination of Keewatin volcanism was followed by the emplacement of the Laurentian intrusions of Lawson (1913) and then by uplift and erosion. The Grassy Island and Bad Vermillion Lake plutons are dated at 2695 m.y. and intruded into older volcanics but rose rapidly enough to supply sediment to the younger rocks. After the emplacement of the tonalites, the region was probably one of substantial relief. Erosion of the highlands was probably rapid, as indicated by the composition and textural immaturity of the conglomerate matrices. Unroofing of the plutons produced several tonalite-bearing conglomerate beds. Though feldspathic sandstone makes up the bulk of the accumulation, lenses of conglomerate are found at many horizons. There is no evidence to suggest that the tonalitic cobbles have been derived from a pre-Keewatin source. Following the deposition of the granite-bearing conglomerates of units 1 and 2 (Figure 3.1), the physiographic conditions, for the eastern area, had been altered such that the environment was receiving no coarse granitic detritus.

The tectonic setting of the Seine Group in the context of the Archean would not be represented by today's tectonics. Table 8.1 highlights many workers' interpretations of tectonic models for the subprovince (from Blackburn and others, 1985).

The best model for alluvial sedimentation for the lower conglomeratic units would include both volcanic rocks and uplifted intrusives shedding detritus, and would be similar to the Sierra Nevada alluvial fans of today. Proximal deposits consist of orthoconglomerate; matrix-supported units or resedimented units are absent. Distal deposits

	WILSON *ET AL.* (1974)	GOODWIN (1977)	YOUNG (1980)	DOUGLAS AND PRICE (1972)	LANGFORD AND MORIN (1976)	BLACKBURN (1980)
1) Preexisting Basement	simatic	sialic	sialic	sialic	sialic	sialic
2) Basement to Volcanoes	simatic	simatic	sialic	simatic	simatic	simatic
3) Source of Volcanic Magmas	fractional crystalization of molten mantle	mantle plume-partial melt	mantle plume	subducted oceanic crust	subducted oceanic crust	mantle melt and subducted oceanic crust
4) Volcanic Types Preserved	layered volcanic complex	oceanic crust	n/a	island arc	island arc, back arc	oceanic crust, island arc, back arc
5) Nature of Marginal Belts	younger aulacogens	rift basin parallel to volcanic basin	"compressive" basin	pericratonic basin	forearc basin	n/a
6) Sedimentary Provenance	volcanic	dominantly sialic	volcanic	sialic	volcanic	volcanic
7) Source of Batholiths	fractionated residual liquid from mantle	partial melt of sagging mafic crust	melt from sialic crust	subduction of oceanic crust	subduction of oceanic crust	subduction of oceanic crust
8) Symmetry about the Central Axis of the Wabigoon Subprovince	random	bilateral	bilateral	asymmetric	asymmetric	bilateral

Table 8.1 Blackburn and other's (1985) implications of tectonic models of various workers for the Wabigoon Subprovince.

consist of feldspathic sandstone with abundant trough and planar cross-bedding. Changes from dominant conglomerate to dominant feldspathic sandstone are most likely related to position on the fan relative to major channels. A setting similar to Figure 8.1 is proposed, such as for the Paleozoic Cannes de Roche Formation (Rust, 1978). Turner and Walker (1973) maintained that gravels will be deposited close to the mouth of a major channel, whereas laterally and downstream there will be sand deposited by sheetflood mechanisms.

Blackburn and others (1985) suggested that the western Wabigoon subprovince contains a number of volcanic centers in overlapping states of development. They showed that all available data suggest that mixed calc-alkaline to tholeiitic sequences were deposited over time spans of about 45 m.y., from 2755-2711 m.y. Post-tectonic stocks have ages from 2700-2695 m.y. Considering the extended time span for development of the volcanic sequences, dates of batholithic emplacement suggest that calc-alkaline volcanism is associated with batholithic emplacement. Remember that although stratigraphic successions have been established, correlation between volcanic sequences is still unlikely.

Davis and others (1986) dated the Bad Vermillion Lake pluton at 2729 +/- 3 m.y., similar to the age of 2728 +/- 5

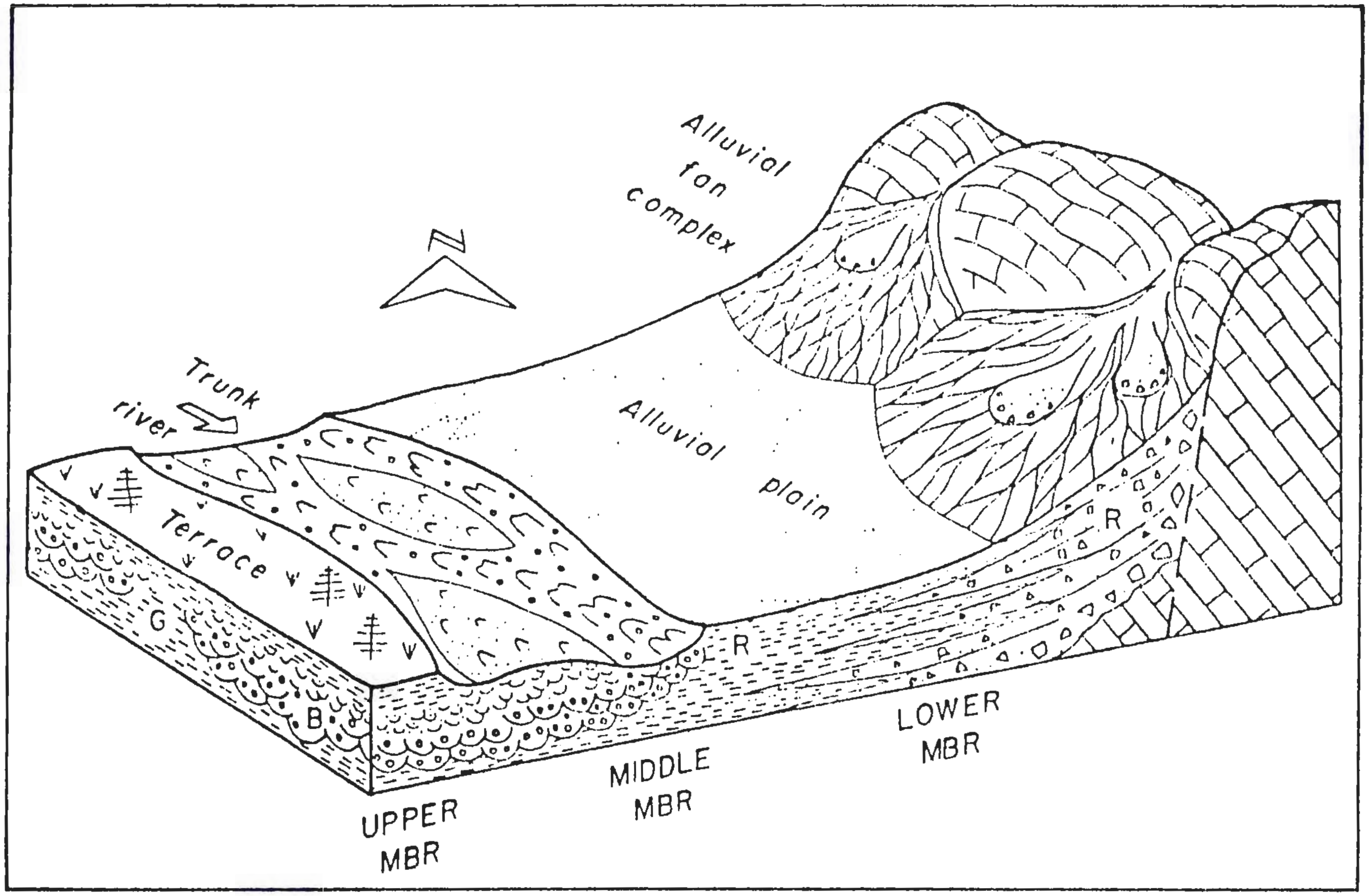

Figure 8.1 Depositional model for the Cannes de Roche Formation by Rust (1978). Seine Group conglomerate and sandstone are probably a deposit of this model.

m.y. for the overlying rhyolite. They suggested that the sill represents subvolcanic chambers for the rhyolite magmatism. Davis and others' date for the trondhjemite clast of 2695 +/-3 m.y. yields a maximum age for the Seine conglomerate, while a minimum age is suggested by the 2686 +/- 1 m.y. age for the Ottertail stock marking the end of regional deformation. They emphasized that deposition and deformation of the Seine Group is tightly bracketed within a period of 9 +/- 4 m.y.

There is lithological correlation between the western part and the eastern part of the study area within the feldspathic sandstone and similarity of iron-formation-bearing sedimentary sequences.

It should be noted that time correlation of volcanic rocks within the belt suggest that similar environments were developed at different times. Blackburn and others (1985) reported that zircon U-Pb geochronology showed that Archean processes in the western Wabigoon occurred within about 60 m.y. This is considerably shorter than the span of orogenic activity at modern continental margins which is approximately 200 m.y. (Blackburn and others, 1985).

Davis and others (1986) noted that the area must have been affected by at least two deformations, as the Seine Group lies unconformably upon older Keewatin volcanics and intrusives while it itself is deformed. This is supported by the metamorphosed volcanic (particularily greenschist and biotite schist) fragments discovered in this study.

Until the early 1970's, most workers compared greenstone belts to geosynclines, but volcanic rocks are more voluminous than in Phanerozoic geosynclines. Turner and Walker (1973) suggested that comparisons with classical geosynclinal basins are tenuous. They pointed out that younger geosynclines do not have the flysch sequence overlain by the molasse.

Two main categories of models of Archean crustal development include those of unique Archean processes and those of strict uniformitarianism. Critical differences among the types include the nature of the crust, source of magmas, and relationships to other subprovinces. Wilson and others (1974) proposed a model of a molten upper mantle capped by oceanic crust. All magmas were derived from fractional crystallization of the melt.

The basin concept was used by Goodwin (1973) who proposed that the Superior Province developed as a number of basins and cratons. His criteria for basin margins was criticized by Walker, suggesting tht the basin margins are highly subjective. Walker (1978) suggested the existence of an Archean ocean and many small landmasses. All data suggest that the major sedimentary basins were marginal to the Wabigoon Subprovince which was undergoing partial emergence.

Young's (1978) basinal model suggested a floor of sialic crust. Langford and Morin (1976) applied tectonics to the Superior Province and the Phanerozoic Cordilleran belts of western Canada. They suggested the volcanic sequences of this study area were separated by an ocean from a craton which represented the Berens River and Gods Lake Subprovinces. The model suggests a fore-arc environment to the south of the volcanic arc and a back-arc environment to the north.

Blackburn (1980) proposed the model depicted in Figure 8.2. He proposed the Wabigoon subprovince represents a complete Wilson Cycle with a "micro-ocean" that opened and closed as the area developed. Recent geochronologic data support this model.

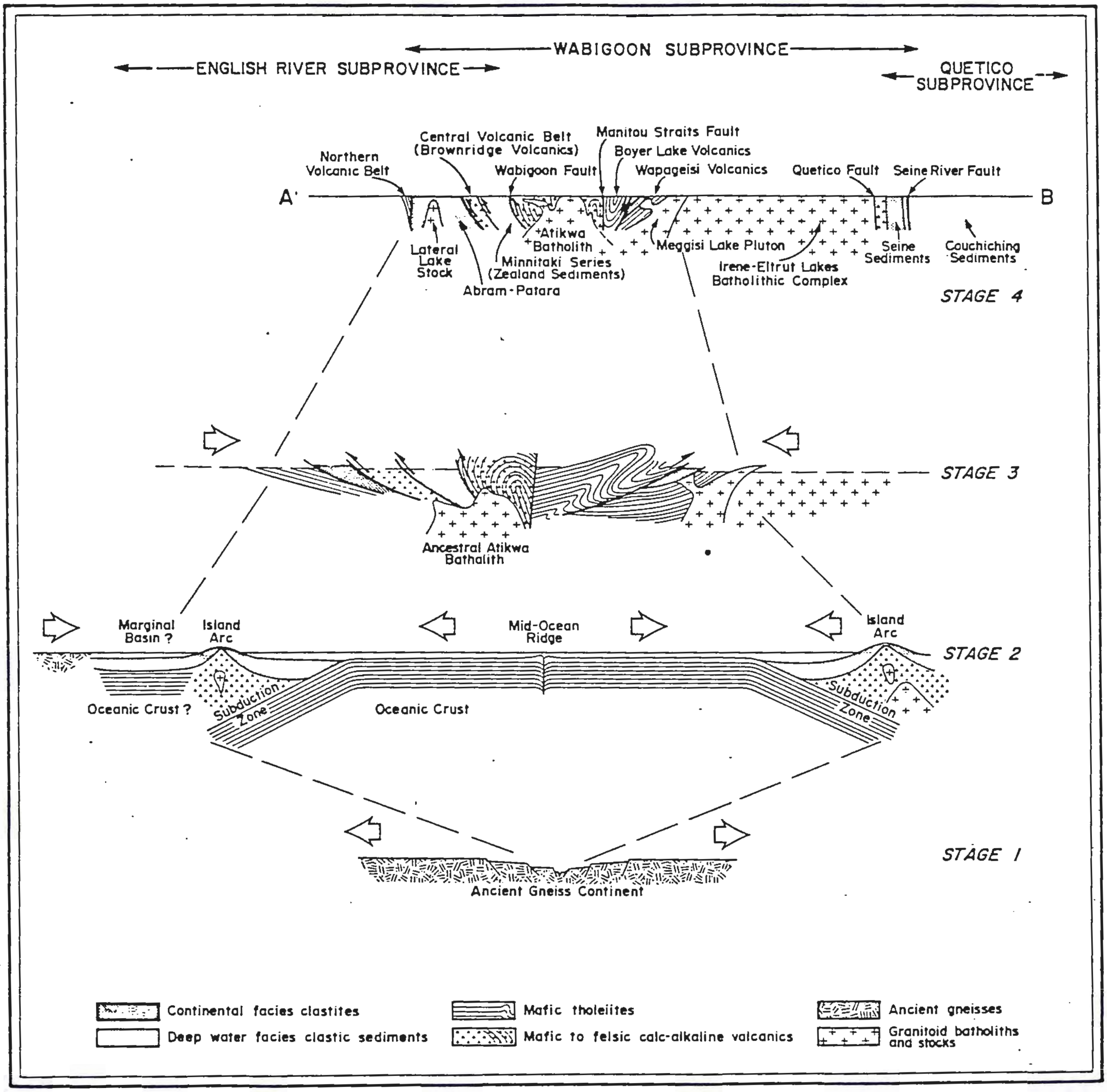

Figure 8.2 Blackburn's (1980) tectonic model for development of the Superior Province (From Blackburn and others, 1985).

Chapter 9

CONCLUSIONS

1) The Seine Group in the Rainy Lake-Mine Centre area in Minnesota and Ontario consists of an assemblage of steeply dipping sedimentary rock types including orthoconglomerate, feldspathic sandstone, fine-grained schistose sediments, and banded iron-formation. The age of the Seine Group is 2690 +/- 9 m.y. based on the most recent Rb-Sr data.

2) The Seine Group in the eastern part of the study area is divided into a lower conglomerate member and an upper feldspathic sandstone member that contains abundant fine-grained beds and local banded iron-formation near the top. The Seine Group in the western part of the study area is divided into a lower feldspathic sandstone member and an upper orthoconglomerate member.

3) Stratification in the area generally is vertical or nearly vertical, and strikes east-northeast. The regional metamorphic grade is upper greenschist. Characteristic metamorphic minerals include quartz, biotite, muscovite, and minor chlorite.

4) Microscopic examination of thin sections shows a distribution of rock types similar to that noted in megascopic modal anlyses of pebbles, cobbles, and boulders.

5) The Seine Group-Algoman unconformity varies from one

area to another. Where it is exposed, the basal conglomerate lies nonconformably upon the Bad Vermillion Lake pluton. There is no regolith preserved where the conglomerate lies on the pluton.

6) Provenance of the detritus was largely from felsic volcanic and tonalitic intrusive terrane located within and to the north of a depositonal basin. Data from thin section modal analyses suggest a magmatic arc provenance when applied to QFM and QmFLt triangles for determining provenance of Phanerozoic sandstones and the abundant quartz input from plutons is taken into account. Minor portions may have been derived from elsewhere.

7) The felsic plutonic clasts in the western conglomerate are tonalitic as determined by modal analyses, and are identical to the Grassy Island Tonalite in the western part of the area. Near Mine Centre, plutonic clasts in the conglomerate consist of tonalite and gabbro; these are nearly identical to the Bad Vermillion Lake intrusive, suggesting local derivation and supporting evidence of minor movement along the surrounding faults in a motion interpreted as dextral.

8) Paleocurrent measurements indicate generally southerly-flowing currents, and the presence of a south-southeast dipping paleoslope after correction for tilt and plunge in the western part of the study area. In

the eastern portion of the study area, measurements indicate a southwest dipping paleoslope.

9) Processes for transport and deposition of detritus include fluvial transport for the feldspathic sandstones and alluvial processes such as ephemeral flooding and sheetflooding for the orthoconglomerate.

10) The evidence supporting subaerial deposition of the orthoconglomerate and sandstone includes: crude stratification, lack of imbrication, abundant cross-bedding, clast-supported pebbly sand interbeds, and textural and compositional immaturity.

11) The biotite schist and greenstone clasts present in the orthoconglomerate is evidence indicating that a major metamorphic event took place prior to the deposition of the Seine Group.

Bibliography

Ayres, L.D., 1983, Bimodal volcanism in Archean Greenstone Belts, as exemplefied by greywacke compostiion, Lake Superior Park, Ontario: Canadian Journal of Earth Sciences, v. 20, 1168-1194.

Baragar, W. R. and Mcglynn, J. C., 1976, Early Archean Basement in the Canadian Shield: A Review of Evidence: Geological Survey of Canada, Paper 76-14, 20 p.

Blackburn, C. E, 1980, Towards a mobilist tectonic modelfor part of the Archean of Northwestern Ontario: Geoscience Canada, v.7, no.2, p. 64-72.

Blackburn, C. E., Bond, W. D., Breaks, F. W., Davis, D. W., Edwards, G. R., Poulsen, K. H., Trowell, N. F. and Wood, J., 1985, Evolution of Archean Volcanic-Sedimentary sequences of the Western Wabigoon Subprovince and its margins: a Review: in Ayres, L. D., Thurston, P. C., Card, K. D., and Weber, W., editors, Evolution of Archean Supracrustal Sequences: Geological Association of Canada, Special Paper 28, p. 89-116.

Blackburn, C. E., and Mackasey, W. O., 1977, Nature of the Quetico-Wabigoon boundary in the DeCourcey-Smiley Lakes area, Northwestern Ontario: Discussion: Canadian Journal of Earth Sciences, v. 14, p. 1959-1961.

Compton, R. R., 1962, Manual of Field Geology: John Wiley and Sons, New York 378 p.

Cram, I.H., 1932, The Rest Island granite of Minnesota and Ontario: Journal of Geology, v. 40, p. 270-278.

Davies, J. C., 1978, Geology of the Shoal Lake-Western Peninsula Area, District of Kenora: Ontario Geological Survey Open File Report 5242, 131 p.

Davis, D. W., and Edwards, G. R., 1982, Zircon U-Pb ages from Kakagi Lake area, Wabigoon Subprovince, Northwest Ontario: Canadian Journal of Earth Sciences, v. 19, p. 1235-1245.

Davis, D. W., Poulsen, K. H., and Kamo, S. L., 1986, Geochronology of the Southern Rainy Lake Area, Northwestern Ontario: Institute on Lake Superior Geology Proceedings, 32nd Annual Meeting, p. 21-22.

Day, W. C., 1983, Bedrock geologic map of the Rainy Lake Area, Northern Minnesota: Open-file Report, United States Geological Survey.

Dickinson, W. R., and Suczek, C. A., 1979, Plate Tectonics and sandstone compositions: American Association of Petroleum Geologists Bulletin, v. 63, p. 2164-2182.

Dickinson, W. R., Beard, L. S., Brakenridge, G. R., Erjavec, J. L., Ferguson, R. C., Inman, K. F., Knepp,R. A., Lindberg, F. A., and Ryber, P. T., 1983 Provenance of North American Phanerozoic sandstones inrelation to tectonic setting: Geological Society of America Bulletin, V. 94, p. 222-235.

Dott, R.L., Jr., Wacke, graywacke, and matrix- what approach to immature sandstone classification?: Journal of Sedimentary Petrology, v. 34, p. 625-632.

Goldich, S.S., Nier, A.O., Baadsgaard, H., Hoffman, J.H.,and Drueger, H.W., 1961, The Precambrian geology and geochronology of Minnesota: Minnesota Geological Survey Bulletin 41, 193 p.

Goldich, S. S., and Peterman, Z. E., 1980, Geology and Geocchemistry of the Rainy Lake Area: Precambrian Research, v. 11, p. 307-327.

Goodwin, A. M., 1968, Archean protocontinental growth and early crustal history of the Canadian Shield: 23rd International Geological Congress, Prague, Proceedings, v. 1, p. 68-69

Grout, F. F., 1925, The Coutchiching problem: Geological Society of America Bulletin, v. 36, no. 2, p. 351-364.

Grout, F. F., Gruner, J. W., Schwartz, G. M., and Theil, G. A., 1951, Precambrian stratigraphy of Minnesota: Geological Society of America Bulletin, v. 62, p. 1017-1078.

Hanson, G. N., 1968, D-Ar ages for hornblende from granites and gneisses and for basaltic intrusives in Minnesota: Minnesota Geological Survey Rept. Inv. 8, 20p.

Harris, F. R., 1974, Geology of the Rainy Lake Area, District of Rainy River; Ontario Division of Mines, Geological Report 115, 94p.

Hart, S. R., and Davis, G. L., 1969, Zircon U-Pb and whole rock Rb-Sr ages and early crustal development near Rainy Lake, Ontario, Geological Society of America Bulletin, v. 80, p. 595-616.

Hooke, R. L., 1967, Processes in arid-region alluvial fans: Journal of Geology, v. 75, p.438-460.

Hsu, M.Y., 1971, Analysis of strain, shape, and orientation of the deformed pebbles in the Seine River area, Ontario; PHD thesis, unpub., McMaster University, 167 p.

Krynine, P.D., 1948, The megascopic study and field classification of sedimentary rocks: Journal of Geology, v. 56, p. 130-165

Langford, F.F., and Morin, J.A., 1976 The development of the Superior Province of Northwestern Ontario by merging Island arcs: American Journal of Science, v. 276, p. 1023-1034.

Lawson, A. C., 1888, Report of the geology of the Rainy Lake region: Geological and Natural History Survey of Canada., 190 p.

-----1913, The Archean geology of Rainy Lake, restudied. Geological Survey of Canada Memoir 40, 115p.

Miall, A. D., 1977, A review of the braided-river depositional environment: Earth Science Reviews, v. 13, p. 1-62.

-----1978, Lithofacies types and vertical profile models in braided rivers: a summary; in A. D. Miall, ed., Fluvial Sedimentology; Canadian Society of Petroleum Geologists Memoir 5, p. 597-604.

-----1982, Analysis of Fluvial Depositional Systems: American Association of Petroleum Geologists Education Course Note Series #20, 75 p.

McGlynn, J. C., and Henderson, J. B., 1970, Archean volcanism and sedimentation in the Slave Structural Province: in Baer, A. J., editor, Basins and Geosynclines of the Canadian Shield: Geological Survey of Canada, Paper 70-4-, p. 31-44.

Merritt, P. L., 1934, Seine-Coutchiching problem, Geological Society of America Bulletin, v. 45, p. 333-374

Nemec, W. and Steel, R.J., 1983, Alluvial and coastal conglomerates: their significant features and some comments on gravelly mass-flow deposits: in: Koster, E.H., and Steel, R.J. (Eds.), Sedimentology of Gravels and Conglomerates: Canadian Society of Petroleum Geologists, Memoir 10, p. 1-31.

Ojakangas, R. W., 1972, Rainy Lake Area: in Sims, P. K., and Morey, G. B., editors, Geology of Minnesota: A Centennial Volume: Minnesota Geological Survey, p. 163-171.

------, 1985, Review of Archean clastic sedimentation, Canadian Shield: mojor felsic volcanic contributions to turbidite and alluvial fan-fluvial facies associations, in Ayres, L. D., Thurston, P.C., Card, K.D., and Weber, W. editors, Evolution of Archean Supracrustal Sequences, Geological Association of Canada Special Paper 28, p. 23-47.

Ojakangas, R. W., and Olson, J. M., 1982, Sedimentation and petrology of Archean feldspathic quartzite and conglomerate (Seine Series Equivalent), Rainy Lake, Minnesota: 28th Annual Institute on Lake Superior Geology Proceedings, p. 36-37.

Peterman, A. E., Goldich, S. S., Hedfe, C. F., and Yardley, D. H., Geochronology of the Rainy Lake region, Minnesota-Ontario, in B. R. Doe and D. K. Smith (editors), Studies in Mineralogy and Precambrian Geology, Geological Society of America Memoir 135, p. 193-215.

Pettijohn, F. J., 1943, Archean sedimentation: Geological Society of America Bulletin, v. 54, p. 925-972.

Pettijohn, F. J., Potter, P. E., and Siever, R., 1973, Sand and Sandstone: Springer-Verlag, New York, 425 p.

Potter, P. E., and Pettijohn, F. J., 1977, Paleocurrents and Basin Analysis: 2nd Edition, Springer-Verlag, New York, 425 p.

Poulsen, K. H., Borradaile, G. J., and Kehlenbeck, M. M., 1980, An inverted Archean sucession at Rainy Lake, Ontario: Canadian Journal of Earth Sciences, v. 17, p. 1358-1369.

Poulsen, K. H., 1982, Archean tectonic evolution at a subprovince boundary, Rainy Lake, Ontario: Geological Association of Canada, Program with Abstracts, v. 7, p. 74.

Poulsen, K. H., 1984, the geological setting of mineralization in the Mine Centre- Fort Francis area, District of Rainy River, Ontario: Ontario Geological Survey Open File Report #5512, 126 p.

Ramsay, J. G., 1961, The effects of folding upon the orientation of sedimentation structures: Journal of Geology, v. 69, p. 84-100.

Rust, B. R., 1978, Depositional models for braided alluvium; in A.D. Miall, ed., Fluvial Sedimentology, Canadian Society of Petroleum Geologists Memoir 5, p. 605-625.

Rust, B. R., and Koster, E. H., 1982, Coarse alluvial deposits: in Walker, R. G., 1984, Facies Models: second edition, Geoscience Canada, Reprint Series 1, Hamilton Ontario, p. 53-69.

Thurston, P. C., Ayres, L. D., Edwards, G. R., Gelinas, L., Ludden, J. N., and Verpaelst, P., 1985, Archean bimodal volcanism: in Ayres, L. D., Thurston, P. C., Card, K. D., and Weber, W., editors, Evolution of Archean Supracrustal Sequences: Geological Association of Canada, Special Paper 28.

Tilton G.R., and Grunenfelder, M., 1968, Sphene: uranium-lead ages: Science, v. 159, p. 1458-1461.

Turner, C. C., and Walker, R. G., 1973, Sedimentology, Stratigraphy, and crustal evolution of the Archean greenstone belt near Sioux Lookout, Ontario: Canadian Journal of Earth Sciences, v. 10, p. 817-845.

Van Hise and others, 1905, Report of the Special Committee for the Lake Superior Region [pre-Cambrian nomenclature], Journal of geology, v. 13, p. 89-104.

Walker, R. G., 1978, A critical appraisal of Archean Basin-Craton Complexes: Canadian Journal of Earth Sciences, v. 15, p. 1213-1218.

Wood, J., 1980, Epiclastic sedimentation and stratigraphy in the North Spirit Lake and Rainy Lake areas: a comparison: Precambrian Research, vol. 12, p. 227-255.

Wood, J., Dekker, J., Jansen, J.G., Keay, J.P., and Panagapko, D. 1980 Mine Center Area (Eastern Half) and (Western Half), District of Rainy River: Ontario Geological Survey Preliminary Maps P. 2201 and P. 2202, Geological Series.

Appendix 1
Modal Analyses of Thin Sections

Sample	MC53C	MC19	RL14A	RL60
Quartz				
Common Quartz	1.3	6.8	3.0	13.6
Polycrystalline Quartz	5.6	14.4	6.7	2.0
Volcanic Quartz		1.0	0.3	1.3
Total Quartz	6.9	22.2	10.0	16.9
Feldspar				
Plagioclase, Fresh	1.7	0.2	7.0	1.0
Plagioclase, Altered	8.0	12.3	5.8	12.5
Alkali Feldspar			0.7	
Total Feldspar	9.7	12.5	13.5	13.5
Rock Fragments				
Volcanic, Felsic-Intermediate	36.2	22.7	43.6	26.3
Volcanic, Mafic	7.0	3.5	4.0	0.7
Greenschist				
Plutonic (Quartz-Plagioclase)	11.3	10.8	3.0	8.3
Schist (Biotite)	4.3			1.0
Sandstone (Feldspathic)		0.5		0.2
Chert	2.5	5.2	3.0	1.2
Carbonate/Quartz	2.7	1.3	7.0	7.5
Other	0.7			0.3
Total Rock Fragments	57.2	42.5	60.6	45.0
Muscovite	0.2	0.3	0.5	
Biotite	1.7	0.5	0.3	2.2
Epidote				
Chlorite		2.7	0.2	
Opaques				
Limonite	0.2			0.3
Hematite		0.3	4.5	0.8
Iron Carbonate				
Pyrite	0.8			0.3
Magnetite			0.2	
Matrix				
Matrix Mica	11.7	8.3	11.7	12.7
Matrix Quartz-Feldspar	3.2	8.0	6.2	7.3
Total Matrix	14.9	16.6	17.9	20.0

Modal Analyses of Thin Sections (continued)

Sample	RL17	RL56A	RL57	RL63
Quartz				
Common Quartz	30.3	27.3	37.8	31.3
Polycrystalline Quartz	13.7	16.8	7.5	16.7
Volcanic Quartz			0.2	0.3
Total Quartz	44.0	44.1	45.5	48.3
Feldspar				
Plagioclase, Fresh	5.0	9.5	6.2	8.9
Plagioclase, Altered	6.5	4.2	10.2	5.7
Alkali Feldspar	0.3			
Total Feldspar	14.5	13.7	16.4	14.6
Rock Fragments				
Volcanic, Felsic-Intermediate	6.5	8.3	6.0	5.2
Volcanic, Mafic	0.2		0.8	0.2
Greenschist				0.2
Plutonic (Quartz-Plagioclase)	9.3	7.7	6.0	5.5
Schist (Biotite)				
Chert	2.0	0.8	1.0	1.2
Sandstone (Feldspathic)				
Carbonate/Quartz				
Other	0.3		0.2	
Total Rock Fragments	18.3	16.8	14.0	12.1
Muscovite		0.3	0.2	
Biotite			0.3	0.2
Epidote	3.0	0.7	0.3	0.2
Chlorite	0.5	0.7	0.7	
Opaques				
Limonite			0.2	0.3
Hematite		3.2	1.9	0.3
Iron Carbonate	1.7	1.3	1.2	3.0
Pyrite	0.2			
Magnetite			1.0	0.4
Apatite			0.2	
Matrix				
Matrix Mica	10.2	9.4	9.5	13.0
Matrix Quartz-Feldspar	6.5	4.0	8.5	7.2
Total Matrix	16.7	13.4	18.0	20.2

Modal Analyses of Thin Sections (continued)

Sample	RL79	RL27	RL10B	IF80
Quartz				
Common Quartz	16.5	23.7	30.3	21.5
Polycrystalline Quartz	33.3	31.5	18.7	21.8
Volcanic Quartz			0.7	
Total Quartz	49.8	55.2	49.7	43.3
Feldspar				
Plagioclase, Fresh	4.8	9.0	16.0	17.0
Plagioclase, Altered	1.8	1.0		3.5
Alkali Feldspar			1.5	
Total Feldspar	6.6	10.0	17.5	20.5
Rock Fragments				
Volcanic, Felsic-Intermediate	7.8	8.0	1.8	5.5
Volcanic, Mafic			0.5	
Greenschist	0.3		0.2	
Plutonic (Quartz-Plagioclase)	8.5	8.9	6.0	6.3
Schist (Biotite)				
Chert	2.0	2.0	3.0	1.7
Sandstone (Feldspathic)				
Carbonate/quartz				
Other	0.7			
Total Rock Fragments	18.3	18.9	11.5	13.1
Muscovite	0.8	0.2	0.3	0.2
Biotite	1.2	3.5	5.5	
Epidote	3.5	0.5		0.2
Chlorite	5.8	0.7	1.5	0.2
Opaques				
Limonite				
Hematite	1.3	0.6	0.7	1.0
Iron carbonate				3.0
Pyrite		0.3		1.0
Apatite	0.2			
Magnetite	0.2	0.2		
Matrix				
Matrix Mica	2.5	6.2	8.8	12.3
Matrix Quartz-Feldspar	8.3	4.6	8.8	5.3
Total Matrix	10.8	10.8	17.6	17.6

Modal Analyses of Thin Sections (continued)

Sample	IF256	IF670	RL14A2
Quartz			
Common Quartz	22.0	30.8	42
Polycrystalline Quartz	31.5	16.3	4
Volcanic Quartz			
Total Quartz	53.5	47.1	46
Feldspar			
Plagioclase, Fresh	5.0	6.7	20
Plagioclase, Altered	4.2	7.7	
Alkali Feldspar			
Total Feldspar	9.2	14.4	20
Rock Fragments			
Volcanic, Felsic-Intermediate	6.9	5.6	5
Volcanic, Mafic	0.5		3
Greenschist	0.2		
Plutonic (Quartz-Plagioclase)	4.8	1.3	2
Schist (Biotite)			
Chert	1.5		2
Sandstone (Feldspathic)			
Carbonate/quartz			
Other			
Total Rock Fragments	13.9	6.9	12
Muscovite	2.3		
Biotite	0.5	4.2	3
Epidote	0.2		
Chlorite	0.5		
Opaques			
Limonite		0.3	
Hematite	2.0	0.3	
Iron carbonate	2.7		
Pyrite			
Magnetite	0.3		
Matrix			
Matrix Mica	6.8	15.0	10
Matrix Quartz-Feldspar	7.5	8.5	11
Total Matrix	13.3	23.5	21

Modal Analyses of Granitic Thin Sections

Sample	MC5	MC114	MC118	RL102	RL102B
Quartz	31.0	26.0	39.0	36.0	32.0
Feldspar					
Plagioclase	61.5	56.5	49.0	55.0	61.0
Alkali Feldspar	2.5	0	2.0	1.5	0
Total Feldspar	64.0	56.5	51.0	56.5	61.0
Carbonate	3.0	4.5	8.0	4.0	3.0
Biotite	2.0	0	1.0	1.5	2.5
Chlorite	0	12.0	1.5	3.0	2.0
Opaques					
Iron carbonate	0	0	0	0	0
Pyrite	0	1.0	0	0.5	0
Magnetite	0	0	0	0	0

Modal Analysis of Schistose Sandstone Thin Sections

Sample	MC31	MC37	MC40	MC46	MC48
Quartz	46	35	50	44	58
Feldspar					
Plagioclase	44	25	23	34	21
Alkali Feldspar	1	0	9	2	6
Total Feldspar	48	25	32	36	27
Micas					
Biotite	-	15	-	5	-
Muscovite	-	20	-	10	-
Chlorite	-	5	-	5	-
Total Micas	8	40	18	20	15

Appendix 2

Cross-bedding measurements are listed in the following table. The column titled "type" denotes the type of cross-bedding observed in the field: t, trough cross-bedding; p, planar cross-bedding; and a, trough axis measurement. The column titled Bedding Azi./inc. denotes the bedding azimuth and inclination for the bedding at the particular measurement location. The bedding azimuth is the direction 90 degrees from the strike direction in the direction of dip. The inclination is the amount of dip in the bedding azimuth direction. The column titled "Cross-bed Azi./inc." denotes the cross-bed azimuth and inclination. The column titled "Correct 1" denotes the cross-bedding azimuth and inclination corrected for simple tilt using a stereonet. The column titled "Correct 2" denotes the cross-bedding azimuth and inclination corrected for tilt and plunge using a stereonet. The column titled "Linea. Azi./plunge" denotes the corresponding lineation measurement and plunge used in the correction for tilt and plunge.

Appendix 2
Paleocurrent Data

Sta.	Type	Bedding Azi./inc.	Cross-bed Azi./inc.	Correct 1	Correct 2	Linea. Azi/plunge
RL-27	t	165/85	190/88	250/25	222/25	61/31
	t	170/90	200/83	270/30	88/28	
	t	170/90	207/90	260/38	107/34	
	a			199	186	
	a	165/80ot		188	192	
	a			196	193	
	a			195	195	
RL-32	a			105	110	58/34
	a			228	215	
	t	178/87	200/86	272/22	110/24	
	t	178/87	168/82	64/12	151/10	
	t	175/88	190/90	258/15	118/12	
	t	175/88	194/88	265/18	116/9	
MC-36	p	170/85	188/85	259/7	230/18	182/78
	p	170/90	175/89	261/5	95/5	
	a			185	240	
MC-38	t	164/76	175/73	272/10	295/10	254/37
	p	149/66	175/82	210/28	230/24	
	t	165/76	180/85	227/19	254/18	
MC-54	a			98	96	254/37
RL-57	p	177/85ot	195/80ot	250/20	136/18	64/36
	t	177/85ot	202/85ot	241/18	122/26	

RL-63	p	203/90	221/90	294/17	142/17	64/36
RL-64	a			149	157	
RL-65	p	180/90	213/90	264/34	126/32	
RL-66	t	177/90	209/90	266/32	123/50	72/40
	p	167/90	183/88	256/16	216/16	
	p	177/90	216/89	265/29	123/38	
	p	177/90	199/90	266/23	130/25	
	t	177/90	165/89	90/12	303/8	
RL-67	t	203/90	224/90	292/20	133/20	62/31
	p	203/88	178/90	134/45	134/20	
	t	203/90	258/87	294/52	138/32	
	t	203/90	261/90	295/20	135/58	
RL-70	p	163/85ot	175/85ot	250/16	110/15	62/31
RL-82	p	180/83	197/78ot	220/14	158/25	74/29
	p	174/90	190/88	264/16	105/21	
RL-83	p	171/73	182/76	242/12	222/12	74/29
RL-86	t	180/85	197/20	252/18	140/20	74/29
RL-88	t	191/90	145/88	101/45	309/40	68/33
	t	191/90	156/90	107/41	182/42	
	t	181/90	199/90	270/18	126/18	
	p	177/90	196/90	266/18	119/18	
RL-89	t	162/90	205/90	252/42	110/42	61/31
	t	162/90	201/90	251/39	112/38	
RL-104	a	158/90		165	162	
RL-105	p	186/85ot	200/85ot	270/17	127/18	

	p	202/90	188/90	110/16	316/10	
MC-122	a		248		254	70/50
	a		246		250	
	t	115/50	145/90	156/47	100/8	
MC-123	p	146/82	145/90	143/8	148/12	58/48
	a	146/82	160/80ot	162/14	158	
	a	154/90		216	190	
	t	154/90	174/90	244/20	106/20	
	t	154/90	170/90	245/16	110/11	
MC-124	t	146/90	170/90	263/23	151/10	53/60
	t	146/90	130/90	58/16	105/20	
	t	146/90	158/90	235/12	202/8	
	p	146/90	188/90	236/42	194	
	t	146/90	160/90	234/14	199/12	
	t	146/90	163/90	237/18	190/14	
	t	146/90	122/90	56/25	191/14	
MC-128	t	164/90	184/90	254/20	124/18	53/60
	t	164/90	185/90	253/21	124/12	
	t	164/90	132/90	75/23	291/28	
	a			156	146	
MC-144	t	158/90	190/90	247/32	193/13	
	t	158/90	186/90	248/28	188/15	
	p	150/90	170/90	240/20	194/20	
	p	150/90	168/90	241/18	196/18	
	p	150/90	146/90	68/4	200/8	

RL-151	t	165/90	180/90	254/13	137/12	60/35
	t	156/90	222/90	255/56	114/30	
	t	174/90	210/90	264/37	109/31	
	t	170/90	195/90	262/22	98/25	
RL-153						
RL-156	p	174/90	162/90	87/12	107/8	60/35
	t	168/90	195/90	257/27	144/25	
	p	160/90	177/90	256/27	151/8	
	t	146/85	198/90	236/49	141/18	
	t	174/90	193/90	102/18	143/25	
	t	175/90	158/90	250/16	320/15	
RL-157	t	170/90	160/90	248/10	144/15	74/40
	t	183/90	208/90	273/26	141/32	
	t	175/90	195/90	263/21	138/22	
	p	174/90	193/90	262/35	140/20	
	t	173/90	160/90	87/12	328/15	
	t	170/90	153/90	81/12	325/18	
	t	172/90	189/90	251/28	139/23	
	t	172/90	188/90	250/26	140/21	
	t	173/90	202/90	252/38	142/16	
RL-161	t	163/90	147/80ot	170/17	292/14	
RL-165	t	179/90	215/90	264/15	147/40	59/30
	t	179/90	211/90	267/19	149/25	
	t	162/90	141/90	116/10	319	
	t	162/90	212/90	263/18	148/50	

	a			181	170	
RL-166	t	171/90	203/90	268/14	141/28	
	t	171/90	192/90	257/18	138/21	
RL-168	p	171/90	183/90	259/14	142/15	62/35
	p	171/90	190/90	261/22	138/18	
	t	171/90	198/90	254/13	141/26	
	t	171/90	207/90	249/17	137/15	
RL-172	t	175/90	190/80ot	238/20	179/21	68/30
	t	175/90	172/90	102/18	165/3	
RL-179	p	175/90	177/90	241/23	178/14	
RL-183	t	175/90	147/90	134/13	180/20?	82/30
	t	150/90	152/90	248/21	151/20	
	t	175/90	210/90	268/13	132/18	
	p	145/90	155/90	243/18	149/	
RL-185	t	160/90	209/90	250/16	131/36	82/30
	t	160/90	128/90	111/14	180/2	
	t	160/90	206/90	252/29	132/29	
	t	160/90	206/90	252/29	132/29	
RL-187	t	181/90	204/90	218/19	142/21	82/30
	p	181/90	208/90	216/22	145/28	
RL-188	t	181/90	197/90	219/28	164/13	
	t	181/90	185/90	268/13	147/14	
RL-189a	t	171/90	150/90	248/16		
	p	171/90	160/90	247/10		
	t	171/90	234/90	204/9		

	p	131/90	164/90	226/18		
	p	131/90	200/90	214/18		
RL-192	t	174/90	196/90	261/16		
RL-193	p	176/90	197/90	263/18		
	t	182/90	197/90	251/17		
	t	174/90	199/90	262/19		
	t	183/90	214/90	266/20		
	t	194/90	224/90	288/14		
	t	164/90	204/90	259/13		
	t	175/85ot	156/76ot	219/20		
	t	181/90	161/90	118/13		
	t	175/90	NA			
	p	180/90	203/90	268/4		
	p	180/90	197/90	252/17		
	a			192		
RL-195	t	171/90	198/90	264/18		
RL-197	t	166/83	183/58ot	256/15	142/10	71/32
	a			165	153	
RL-198	p	194/80ot	205/90	264/18	131/14	
	p	194/80ot	205/90	264/18	131/14	
RL-225	t	180/69	211/80ot	266/20		
	t	180/69	184/75ot	259/18		
	t	180/69	209/80ot	258/19		
	t	173/80ot	195/88	264/18		
	t	174/80	203/87	255/16		

	t	174/80	216/75	266/22		
RL-226	t	156/75	201/84	236/18		
	p	176/70ot	153/79ot	248/12		
RL-230	t	164/76ot	138/39ot	278/11	146/12	76/31
RL234	a			170	165	76/31
	p	173/84ot	159/79ot	188/19	128/16	76/31
RL245	t	176/86	200/86	256/19		
RL-246	p	171/86	191/90	258/18		
RL-248	t	145/80ot	131/75ot	164/20		
	t	145/80ot	164/72ot	126/28		
RL-250	t	176/88ot	188/82ot	134/15		
	t	176/88	144/59ot	221/28		
		181/85	151/76	144/21		
RL-266	t	182/80ot	201/65ot	181/30		
MC-282		181/80ot	153/74ot	204/28	130/20	80/60
	a			198	186	
	t	191/80ot	161/74ot	218/16	121/18	
	a			90	266	
	a			94	270	
	a			81	282	
	a			80	289	
		191/80ot	181/63ot	242/15	119/10	